Concept Development of Installation Technology for Rainforest Audio Monitoring Devices

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Abstracts

Rainforest deforestation is the second largest anthropogenic source of greenhouse gas emission into the atmosphere, after the burning of fossil fuels. Up to 90 per cent of tropical rainforest deforestation is conducted illegally. Rainforest Connection endeavour to reduce this number through the installation of up-recycled Audio Monitoring Devices installed high in the trees of the forest.

The presented work aims to assist Rainforest Connection in their mission through the application of concept development methods for the enhancement of installation operations performed in the field. Due to the nature of the company a premium is placed on immediately implementable techniques. In response, both incremental improvements to current operations, through the adoption of industry techniques and commercially available equipment, and novel generated solutions are provided.

The paper recommends the employment of extendable carbon fibre poles for the installation of the Audio Monitoring Devices as a novel solution and identifies a path forward for further development of the installation technique. The adaption of commercial telescopic carbon fibre poles from the window washing industry represents an additional tool for field operations that has the potential to save hours per temporarily installed device; while providing an immediate pathway for field trials in Ecuador at a low investment cost. A segment carbon fibre pole is recommended for future development of high elevation, permanent installations performed from the ground.

Keywords Concept Generation; Product Development; Tropical Rainforest; Remote Rainforest; Customer Needs; Remote Installation; Iterative Process

Preface

The work for the Master's thesis was conducted for Rainforest Connection in 2016.

Special thanks and gratitude are extended to Professor Kalevi Ekman for his patience, understanding, and ever calm guidance through the often murky waters of product development, along with the freedom to fully explore the problem in novel ways.

Thanks are also extended to Rainforest Connect for the opportunity to part take in such an important and rewarding project, particularly Dave Grenell and Topher White for their continued support and for their time in explaining their operations in great detail.

Espoo, 24.4.2017

Gary J. Paddick

Dedication

The work presented here is dedicated to all the friends and family without whom it would not have been possible. To my colleagues for their ideas in steamy saunas and late night brainstorming sessions. To my wonderful room mates and their happy surrender of the living room for months at a time. To my friends and family that never lost faith in myself or the project, and whom always provided a place to rest my head. None of this would have been possible without your enduring love and support.

Sincerely,

Gary J. Paddick

Table of Contents

Appendices

Acronyms

AMD Audio Monitoring Device

API Application Programming Interface

DdRT Doubled Rope Technique

DIY Do It Yourself

DRT Double Rope Technique

HMA Hot Melt Adhesion

MAD Motorized Ascending Device

NGO Non-Governmental Organization

RFCx Rainforest Connection

SOA State of the Art

SPRAT Society of Professional Rope Access Technicians

SPY Finnish Tee Care Association

SRT Single Rope Technique

UAS Unmanned Aircraft Systems

UAV Unmanned Aerial Vehicles

USD United States Dollars

1 Introduction

1.1 Background - Rainforest Deforestation

Mankind induced climate change is one of the greatest challenges of our times. The release of carbon dioxide and other greenhouse gases into the atmosphere has resulted in a steady increase in global temperatures. The effects of which are being experienced worldwide, in the form of variations to weather patterns, an increase in the severity of storms, droughts, water scarcity, and rising sea levels; with the poorest and most vulnerable populations already bearing the brunt of these consequences. The severity of the problem is at long last being acknowledged by world leaders as embodied by the signing of the Paris Agreement in 2016 that aims to halt the increase of global average temperature to well below 2 degree Celsius.

In the fight against climate change, living forests are considered crucial as they absorb and store carbon dioxide from the atmosphere. While it is the combustion of fossil fuels that receive the bulk of media and worldwide attention, as made manifest through the "Keep it in the Ground" divestment campaign, "deforestation is the second largest anthropogenic source of carbon dioxide to the atmosphere, after fossil fuel combustion (Van der Werf et al., 2009)." In fact, deforestation is estimated to account for 17 percent of all man induced global carbon emissions, with the majority of deforestation taking place in the tropical rainforests of the world. Emissions from rainforest deforestation represent 50 percent greater emissions from all the worlds transportation combined; including aviation, road, rail, and shipping traffic. (Nellemann et al., 2012)

Yet there is always hope. Recent studies by INTERPOL have identified that 50 to 90 percent of all forestry activities in key producer tropical forests occur illegally (Bank, 2009). This provides a legal channel to combat both rainforest destruction and worldwide climate change. Reduction in deforestation, particularly through combating illegal logging has been identified as one of the, "fastest, most effective, and least controversial means to reduce global emissions of climate gases (Nellemann et al., 2012)."

1.2 Rainforest Connection

Enter Rainforest Connection (RFCx), a non-profit startup from the United States that seeks to combat rainforest deforestation caused by illegal logging through the use of a real time, remote audio sensing platform. After identifying a gap in the global effort to detect illegal logging at the source - the majority of technological applications to combat deforestation have centred on satellite images which only identify the damage after it has occurred - they developed a system that employs Audio Monitoring Devices (AMDs) installed in and under the tree canopy of the rainforest to identify sound signatures associated with illegal activity, such as chainsaws and heavy equipment. The AMDs utilize the available cellular signal found in the periphery of many rainforests to transmit audio data to a cloud Application Programming Interface (API) that computes the data in real time. Once detected the system provides an alert to the appropriate authorities on the ground, in the form of an e-mail or a SMS message. These alerts include the location of the illegal activity and allow for direct intervention of the illegal logging operation.

RFCx are currently in the pilot phase of their operations, with 2.5 pilots completed to date. Pilots have occurred in Indonesia, Cameroon, the Brazilian Amazon, with future projects planned for Ecuador and Peru. It is from these pilot programs that field conditions, operational data, and areas for improvement are identified.

1.3 Why a new solution is needed

RFCx are at a point in their development where rapid change occurs to their system and working methods in order to meet the challenges of the field encountered throughout the pilot projects. Due to the young age of the product almost all aspects of the system are open to improvement. At the present moment, one concern is their field installation method.

The current installation method calls for the manual climbing of a selected tree through the use of ropes and common arborist techniques. This has been described as a physically demanding and time consuming process that contains environmental hazards. There is uncertainty in the achievable consistency of reaching the intended location upon first ascent of the tree, along with whether the selected location will provide the required cellular signal and sunlight upon ascension. Tree selection has also proven to be an uncertain and time consuming process. These uncertainties, coupled with the physical demands of the climbing process, have accumulated in the desire to explore alternate installation methods.

1.4 Thesis Objectives

The objective of the the thesis is the application of product development, and specifically concept development, methods to identify and develop improvements to the field operations of Rainforest Connection.

Research is conducted to identify the needs of the company, the state of existing technology, and suitability of said technology to be adapted to meet RFCx's needs. Upon evaluation of State of the Art (SOA) technology it will be determined if the generation of novel solutions is required to meet the goals of the company. The specific goals of the project are provided in greater detail in the explicit mission statement presented in section 3.1 and updated in section 9.1.

1.4.1 Project Scope

Free range was given by the RFCx to set the scope of the project; they are open to improvements to any aspect of their system and methods.

Early in the project the scope was limited to activities that related to the physical placement of their existing AMD that would allow for its continual operation, with a focus on decreasing the time and effort required for activities in the field. The project would not look to make major modifications to the AMD or its operation principles. For example, the project would not focus on the use of alternative energy sources to power the AMD to replace the use of solar panels. The scope was further limited to include the installation of only the AMD, and not any additional modular components, such as parabolic antennas or additional solar panel arrays.

The deliverables of the project were agreed upon to be generated concepts for further development, with an emphasis placed on concepts that translate to quick prototyping and feasible implementation. Detailed design would not be part of the deliverables, although there is the option to continue the development of the concepts into fully developed products after the conclusion of the thesis.

1.4.2 Hypothesis

Based on the maturity of comparable industries and the young age of the RFCx's operations, an existing technology, technique, and/or best practice can be adapted - with the potential need for modifications - to meet RFCx's AMD installation needs. As a mature technology, its physical components will be available for off the shelf purchase from existing suppliers.

1.5 Methodology and Thesis Structure

The thesis paper has been structured to highlight both the steps of the concept development process and the inherent iterative nature of the process. The identification of new information throughout the process often necessitates the iteration of a previous step to ensure that the solution that best meets the needs of the customer is discovered and developed. For clarity the project is presented as two cycles or phases. The first phase is described as "Product Discovery" and is characterized by the search and adaptation of existing technologies. This is traditionally the first step in any product development project. The second phase of the project focuses on the generation of novel concepts, and as such is entitled "Concept Generation". While these two stages are presented as distinct stages, it should be understood that overlap occurs in their execution.

Product development, of which concept development is the first step and the focus of this project, can be described as a funnel process. In each stage a wide net is cast in the gathering of information and the search for solutions. As the cycles progress, the development team's understanding of the problem and the solutions available are improved and refined. The distillation of information allows for the contraction of the net cast in iterations in the search for solutions, as the focus of the project is narrowed. A large field of solutions is thus reduced to a few concepts that exhibit the most promise of meeting the goals of the project.

Each cycle of the project moves through similar steps in their completion, as portrayed through the chapter titles of the paper. The steps include the gathering of information to provide the foundation for the phase, the setting of project goals in the form of a formal mission statement, the analysis of the background information to determine the specific criteria that will guide the next step of the cycle; the search for solutions. The results of which are examined and presented in the following section, appropriately entitled analysis and results. Each cycles concludes with a reflection on the process and the determination of the next steps to be taken.

In the first stage of each cycle, information is collected on the task to be completed. This is primarily conducted through communications with the customer, and background information into the operating environment. Overviews of the collected information is presented in chapters 2 and 8.

The second stage condenses the gathered information into a set of specific goals and hopes for the project, presented in the mission statement of the project. The mission statement is a living document that is updated throughout the project and presented in each cycle in chapters 3.1 and 9.1.

The third stage further refines the background information into specific statements that act to guide the search for solutions. The stage is characterized by the development of customer need statements that reflect the express wishes of the customer. In the first cycle - chapter 4 - these statements are converted into the target specifications, consisting of a metric and a value, to direct the search for solutions. In the second cycle - chapter 10 - the problem is decomposed into sub-problems to aid in the development of novel solutions.

The fourth stage, the search for solutions, can be considered the heart of the product development process and project. In the first cycle it is characterized by exploration of the state of the art, or state of the current technology and products available. The ability to adopt an existing technology aids the development of a solution, as it reduces the resources required in its implementation and allows the development team to focus their energy on additional problems. A detailed review of SOA is presented in chapter 5. A thorough comprehension of the SOA facilitates the development of novel solutions in the concept generation phase of the project. For concept generation, the search for solutions is characterized by concurrent external and internal searches, with the external search mimicking the SOA. The internal search is the adaptation of existing knowledge into the development of novel solutions. A detailed review of the external and internal search for solutions is presented in chapter 11.

Upon completion of the search for solutions, the results are reviewed and presented. In the "Product Discovery" phase the results were the recommendation of technologies available for immediate implementation and the identification of promising technologies to be further explored in the "Concept Generation" phase of the project. These are presented in chapter 6. In chapter 12, the generated concepts and solution principles are reviewed and combined into the final solution concepts.

At the conclusion of each cycle, the results are reflected upon to determine their ability to meet of goals of the project; as described by the mission statements, customer needs, and target specifications. After which the next steps of the project are determined. As the true measure of success of the project is the satisfaction of the customer, their reaction is also presented. This information is presented in chapters 7 and 13 respectively.

Part I

Phase 1 - Product Discovery

2 Info: Background Information

Early background information in relation to RFCx's operations were obtained from a variety of sources. Details on the customer's current operations and methods were obtained predominantly through information provided by the customer; including first hand communication through Skype and e-mail, videos and pictures taken in the field, and a pilot project report based on their time working with the Tembé in Brazil.

Additional information on the operating environment of remote rainforests were obtained through traditional research means.

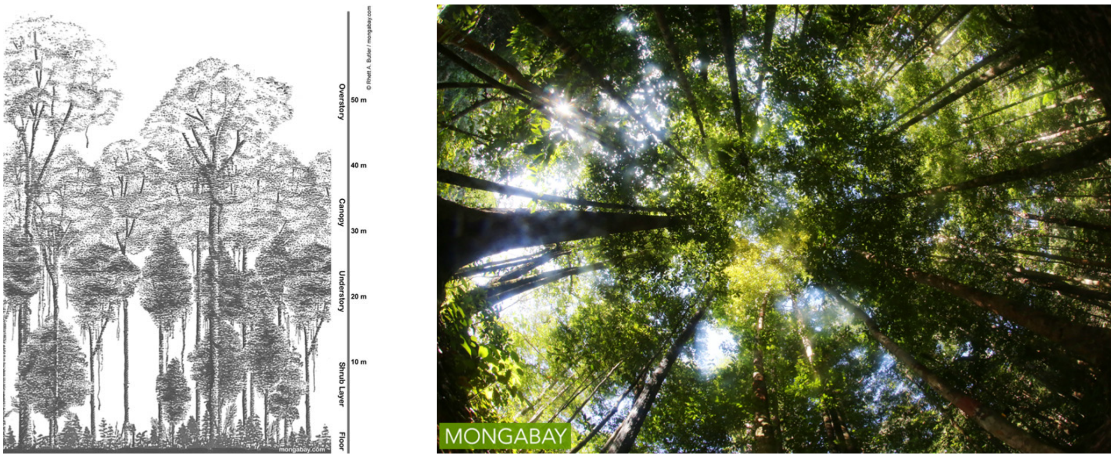
2.1 Operating Environment - Tropical Rainforest

Rainforests are categorized as tropical or temperate depending of their geographic location, with topical rainforests occurring in the equatorial zone between the Tropic of Cancer and the Tropic of Capricorn. While RFCx seek to protect all of the world's endangered rainforests, it is in the tropical forests that they have conducted their operations to date and are the focus of the project.

Tropical rainforests cover approximately 5.9 billion acres (2.4 billion hectors) of land, roughly 16 percent of the Earth's land surface. Their name derives from the high levels of rainfall that they experience and help generate; at least 80 inches (2000 millimetres) per year. Rainforests are characterized by a dense, enclosed tree canopy and a high level of biodiversity.(Butler, 1999-2013) Such a high level that it is possible for a single hector to contain 250 different species of trees (Corporation and Attenborough, 2006).

Even with this high level of diversity, the vertical structure of the rainforest can be generalized by the unique levels of vegetation presented in figure 2.1a. From the ground up they are classified as the forest floor, the shrub layer, the understory, the canopy, and the overstory. The shrub layer is considered the lowest part of the understory, consisting of tree saplings and shrubby plants ranging from 5 to 20 feet (1.5 to 6 meters) from the forest floor. The understory is defined as the collection of widely spaced juvenile and small tree species that form a broken layer below the forest canopy. The canopy forms the ceiling of the forest and consists of the dense branches of the closely spaced canopy trees, whose branches typically begin to spread out 100 to 130 feet (30 to 39 meters) from the forest floor. The canopy can range from 10 to 40 feet (3 to 12 meters) thick. Due to the crowded nature of the trees that form the rainforest canopy, they typically only contain branches near the top of their long, pole like trunks; as depicted in figure 2.1b. The overstory is made up of scattered emergent trees that penetrate through the forest canopy and range from 20 to 100 feet above the canopy, with some species of trees exceeding 213 feet. (Butler, 1999-2013)

The characteristics of the forest floor vary wildly depending on the condition of the forest in question, if it is a primary or secondary forest. A primary forest refers to a forest that is considered undisturbed. The dense canopy above prevents all but 2 percent of sunlight from reaching the forest floor (Corporation and Attenborough, 2006). As such, the forest floor is mostly clear of vegetation - characterized by larger tree trunks and a plethora of seedlings and saplings. Secondary forests are areas of forest that contain light gaps through which sun



(a) Rainforest Canopy Profile

(b) Borneo rainforest

Figure 2.1: Rainforest Profile (Butler, 1999-2013)

light is able to penetrate the canopy ceiling and reach the forest floor. It is in these areas that the dense ground vegetation associated with the term jungle occur. Light gaps occur where the forest has been disturbed, and while they occur naturally at riverbanks and forest edges, they also occur where around man made roads and areas of deforestation. As such, it is likely that most of RFCx's field operations will encounter the dense undergrowth typical of the term jungle.

2.2 RFCx Guardian Phone

RFCx's guardian phone or Audio Monitoring Device (AMD) is an up-recycled, solar powered device that upon installation allows the detection of select audio signatures within a range of a 1 km diameter. The heart of the device is an up-recycled mobile phone, which once outfitted with a high powered microphone is protected from the elements through its complete enclosure in a protective case. For power, the device is outfitted with an array of solar panels (currently numbered at seven), also constructed from recycled materials.

(a) AMD installed on tree

(b) AMD close up

Figure 2.2: AMD installed in rainforest (Rainforest Connection, 2017)

At the moment the system utilizes existing available cell phone networks to enable real time monitoring and computation (although alternatives have been and continue to be explored by the RFCX team).

In some instances, due to a lack of cellular signal and the importance of the creation of a forensic record, AMDs are installed solely as recording devices without the connectivity required for data transmission. In these instances, an operator must physically travel to the location of the AMD, whereby the data stored on the guardian phone is transmitted wirelessly through Bluetooth technology to a hand held device on the ground. The method requires periodic travel to the installation location for the manual collection of the data (currently once per week). Data is then uploaded to the RFCx cloud server and computed in the same manner as the real time streamed data.

2.3 Current Operations and Partners

Field operations to date have consisted of pilot projects in the rainforests of Indonesia, Cameroon, and Brazil, with future projects planned for Ecuador and Peru. In general, field operations are conducted with partners in the field, who invite request RFCx to implement their system in a region of the rainforest to which they have an invested interest. Partners range from indigenous people seeking to protect their land and Non-Governmental Organization (NGO)s associated with them, to government employees and park rangers.

Field activities include the set up of the system through the installation of AMDs, the running of diagnostics, and the training of local partners for the maintenance and further expansion of the system. To date all installation activities are performed by RFCx employees, but future expansion of the system is envisioned to be facilitated by partners in the field. Due to the young nature of the venture, field operations largely revolve around the troubleshooting of new challenges encountered throughout each pilot project.

2.3.1 Current Installation Method

Due to the requirements for access to both cellular signal for data transmission and sunlight for power, the AMDs are installed high above the ground within the trees, currently at a height of 60 to 70 feet (18 – 21 meters) above the forest ground. It hypothesised by the RFCx team that installation at higher elevations may produce both stronger cellular signal and sunlight, aiding in successful 24 hour streaming of audio data. Once installed at such elevations, the AMD is well concealed and virtually invisible from the ground

To reach the required installation height, the tree is ascended by the RFCx crew through the use of rope climbing techniques. A line is shot 60 to 70 feet (18 to 21 meters) into the tree canopy. There are present concerns over the placement of the line with regards to line being close enough to the tree trunk for installation upon ascent of the operator. Observed videos of field operations depict a climbing method that involves the ascension of the rope by kicking off of the tree trunk. Climbing methods are explored in detail in section 5.2.1. Based off the descriptions provided by RFCx the method was identified as a double rope climbing technique. Estimations from the field identify the duration of the ascension process lasting up to 2 hours.

Trees are selected for installation based on both the requirements of the AMD for successful operation - sunlight and cellular signal - and their suitability to be climbed. Prior to being climbed a tree is inspected for safety. Areas of concern include if the branch of the tree is able to support the climbers weight, damage to the tree in the form of rot or cracked branches, and environmental hazards in the form of insects. Ants in particular have been cited as an area of concern.

Once the tree has been ascended, the AMD is positioned in the tree to optimize cellular reception and access to sunlight. The AMD is attached to the trunk of the tree through a variety of fasteners, including screws, wire, horseshoe shaped nails, and zip ties; with a 3D printed mount in development. While at the present time the AMD is installed vertically against the trunk of the tree, other configurations are possible.

Another aspect of field operations is the retrieval of the AMD from the installed tree. Retrieval may be required for a number of reasons, including the non-permanent nature of a pilot project and the unsuccessful selection of the installation location in terms of achieving 24 hour audio data transmission. Device retrieval is performed by re-climbing the tree in which the AMD was installed. The importance of AMD retrieval with respect to installation has been judged by RFCx to be split 80/20 in favour of installation for AMDs with connectivity and a 50/50 split for AMDs installed without connectivity.

2.4 Customer Pain Points

Early communications with RFCx highlighted a number of pain points that the project would seek to address. First and foremost there was a general dislike for the need to climb trees for installation. The process was described as requiring a large amount of physical effort and consuming a great deal of time. Line placement for climbing was also of great concern for a number of reasons. It had been discovered through past field operations that it was possible for the nearest suitable branch for line placement to be located up to 200 feet (60.6 meters) from the ground. This posed problems both in the accuracy of line placement and in the effort required to climb such an extreme height. Outside such extreme conditions, accuracy of line placement was still a major concern due to the dense nature of the canopy and the inaccuracy of their current line placement technique. An even greater pain was experienced in instances where a rope had been climbed only to discover that they were not close enough to the tree trunk to perform an installation, thus requiring the repetition of the process. The safety of the installation method with regards to the risk of falls was also of concern and enhanced by the fact that the nearest medical attention could be hours away.

3 Goal: Mission Statement

3.1 Initial Mission Statement

To provide clear guidance to the product development process, Ulrich (2003) advises the creation of a mission statement to capture the assumptions and decisions already in place that guide development process. The mission statement consists of a brief description of the product that, “avoids implying a specific product concept’, the benefit proposition, and the key goals of the project.

The mission statement developed to guide the first phase of the project is available in table 3.1, page 12. Information expanding on the assumptions and constraints made at time of the mission statement are normally attached to the this mission statement. For our purposes they have been included in section 3.1.5, after a brief overview of the earlier sections of the mission statement.

3.1.1 Product Description

The product description articulates in neutral terms the core objective of the project - a method for installing their audio monitoring devices in remote rainforests. This can include physical equipment and teachable techniques.

3.1.2 Benefit Proposition

The benefit proposition outlines the reasons the product will be deemed a success by addressing the primary complaints and wishes of the customer. At this stage of the project the most vocal complaints were the difficulty and time involved in climbing a tree to install a device, potentially taking from two to three hours and requiring multiple climbs before a successful installation. Efforts were already under way to train local partners in the climbing techniques employed by RFCx to facilitate the expansion of the system.

3.1.3 Key Business Goals

A list of the key goals that support the company’s overall strategy.

Adaptable to a variety of tree characteristics: To support the company’s goal of expanding into endangered rainforests all over the world, the installation method must be adaptable to the wide range of different trees populating each rainforest. These characteristics include trunk and branch thickness, canopy height, surface roughness.

Reduce time from current method: A key area of improvement as identified by RFCx. Improvement in the time required for field installation activities will in turn improve the rate of expansion of monitored rainforest.

Safe method: Any installation technique must be deemed safe for the installer.

Adoptable by partners in the field: Future expansion of the system supported by the installation of devices by local partners.

Shipped as an off the shelf product: For expansion of the system, RFCx envision an off the shelf product that is sent to local partners to install.

Low cost: Required to meet the budget of local partners. The lower the cost, the greater the availability for local partners.

3.1.4 Target Markets

An account of the primary and secondary markets for the product. The primary market are RFCx employees, as they are the ones currently performing installations. The secondary markets are the identified partners in the field with whom RFCx will be working with.

3.1.5 Assumptions and Constraints

A brief expansion on the the assumptions and constraints contained within the mission statement. These statements would be come attached with the mission statement outlined in table 3.1.

Environmentally friendly: Due to the company mission of supporting rainforest conservation and climate change reduction, solutions are to be designed with consideration to their overall environmental impact.

Low impact on trees and environment: Solutions are designed to minimize the local harm to installed upon trees and the immediate surrounding environment.

Less physical effort: For a solution to be adopted by the company and its partners in the field, it will need to require less physical effort than the current climbing method.

Teachable: To facilitate expansion of the monitoring network, the solution operation is to be teachable and repeatable by members of the secondary markets.

Durable: With the inherent lack of supplies available in remote locations, a solution must be able to function for months in the field without access to replacement parts or formal repair facilities.

Compact - Manually carried: Due to the nature of moving through the rainforest and the anticipated lack of motorized vehicles during system installation, a solution should be carry-able by a team of 1 to 3 members and minimize potential snagging on forest undergrowth.

Device requires adjustment during installation: The audio monitoring device requires adjustment at the installation point to optimize cellular signal and sunlight exposure.

Table 3.1: Phase 1 - Mission Statement

Mission Statement: Rainforest Tree Installation Method	
Product Description	• Safe, adaptable technique for the installation of RFCx audio monitoring devices in a wide range of remote rainforest environments.
Benefit Proposition	• Quick and easy installation of device • Requires a low level of training and expertise • Facilitates expansion of monitored rainforest
Key Business Goals	• Adaptable to variety of tree characteristics • Reduce time from current method • Safe method • Adoptable by partners in the field • Shipped as an off the shelf product • Low cost
Primary Market	• RFCx employees
Secondary Markets	• Indigenous people of the rainforest • Government employees • Park rangers • NGOs
Assumptions and Constraints	• Environmentally friendly • Low impact on trees and environment • Less physical effort • Teachable • Durable • Compact - Manually carried • Device requires adjustment during installation

4 Guide: Early Requirements

4.1 Initial Customer Needs

Communications with RFCx - the customer - were recorded throughout the project. Through these communications a number of customer statements were collected. These statements are interpreted to produce the initial customer need statements; statements that are used to guide the Product Discovery phase. The raw customer statements and their corresponding interpreted need statements are presented table 4, the format of which has been supplied by Ulrich (2003, pg. 82). The interrupted need statements express in positive terms the desired attributes of a developed solution, without the specification of how the need is to be satisfied. Terms that evoke a level of importance to a need statement are also avoided.

Examination of the interpreted need statements allows for the majority of the need statements to be classified under five general groupings.

Core Operation: Based on the core working principles of RFCx's audio monitoring device, sunlight (no. 14) and cell service (no. 15) are required for successful operation. The retrieval of the device (no. 9) is non-essential, but considered to add value to a solution.

Time saving: RFCx is looking to improve the time efficiency of all aspects of their field operations. This includes the core installation time (no. 7), time lost due to the inaccuracy of the setup method (no.10), and time spent prior to installation identifying suitable trees for device placement (no. 12).

Designed for Rainforest Environment: Any solution needs to be designed for the operating environment of a remote rainforest (no. 6). This includes transport through the jungle (no. 10), and the variation in trees encountered (no. 13 and no. 18) for installation.

Designed for Local Partners: To meet the company's future goals of expansion any solution should be designed to be operated by field partners (no. 17).

Safety: Any viable solution must be safe for the operator (no. 16).

Table 4.1: Initial Customer Statements and Interpreted Needs

No.	Question/Prompt	Customer Statement	Interpreted Need
1	Goal	An off the shelf product	Solution is an off the shelf product.
2	Current method	Don't want to be on the tree, due to insects.	Solution prevents operator from making direct contact with the tree trunk
3	Current method	General dissatisfaction with the hard physical effort of the current method, of climbing 120 ft in the rainforest.	Solution is low effort

Table 4.1: Initial Customer Statements and Interpreted Needs

No.	Question/Prompt	Customer Statement	Interpreted Need
4	Asking about attachment of AMD to trees	Anyway, I myself am not a big fan of having to print a bunch of extra plastic materials ....given the cost savings of skipping that step and the energy/plastic savings.	Solution is cost/production efficient
5	User audience and ”To date in my mind the right approach is a durable, low tech solution. ”	That sounds correct in terms of something simple that locals can do	Solution is simple
6	Conclusion	A part of our ongoing desire to work in remote unideal areas is because if we can build a system that works reliably in the remote Amazon, we can make it work anywhere.	Solution operates in remote locations
7	Installation time	Installation can take up to 2 hrs. This is too long. Like to cut down by 70%	Solution installs device in $<$ 2 hours
8	In tree adjustment	Right now you need the human element for adjusting the devices in the tree.	Solution allows for device adjustment in the tree
9	Questions on device retrieval	Device retrieval is a common occurrence	Solution retrieves AMD
10	Limiting Factors (in the field)	Canopy makes it difficult to hit target branch with big shot	Solution is accurate in placement
11	Limiting Factors (in the field)	The jungle is dense	Solution is transportable through dense jungle (under growth)
12	Limiting Factors (in the field)	Tree selection is an issue. 5 in 20 may be good to climb	Solution increases the number of trees suitable for installation.
13	Limiting Factors (in the field)	Height of branches. Suitable branches could start at 200 ft. Don’t want to climb that high + trouble with line placement	Solution operates with the nearest branch being 200 feet from the ground.
14	Tree selection	Sunlight matters	Solution installs device in a position (or elevation) that provides sunlight

Table 4.1: Initial Customer Statements and Interpreted Needs

No.	Question/Prompt	Customer Statement	Interpreted Need
15	Installation height	Believed that higher up the tree equals better signal.	Solution installs device in a position (or elevation) that provides strong cell signal
16	Rope climbing concerns	We're worried about the risk that they or someone could fall	Solution reduces risk of fall/injury
17	Target user	We're designing for partners in the field	Solution is designed to be operated by RFCx partners (indigenous people, park rangers, etc.)
18	Thinking of a "Line Crawler" concept	The trees are very irregular	Solution operates on irregular trees

These eighteen statements are the expression of the wants and desires of the customer for their installation method. Although a solution does not need to meet every need to be considered a candidate for future exploration, these statements guide the direction of the next step in the process - the search for solutions.

4.2 Requirements and Device Specifications

It is oft said that customer needs are the language of the customer, while the product specifications are the language of the engineer. From the interpreted need statements outlined in the previous section and the inherent needs attributed to the realities of the company, a set of general requirements are developed to guide the concept development process - the target specifications. Target specifications are viewed as the goals, hopes, and aspirations of the development team. Accordingly, these early target specifications are not to be seen as hard restrictions to potential concept ideas, but as a guide document. The target specifications are presented in table 4.2. Specifications are kept general at this stage of concept development in order to avoid overly influencing the creative side of the search for solutions. Ulrich (2003).

As recommended by Ulrich (2003), each specification consists of a signal metric and value. The logic follows that if each requirement meets a single customer need, then a concept that meets the target specification will also fulfill the associated need. To facilitate this connection between customer need and target specification the associated statement number from table 4 is included. The metrics without a related need are considered inherent requirements of the project. The values of the metrics are obtained from a generalized benchmarking of RFCx's current operations in the field. The rational behind the assigned metrics will be discussed in brief below.

[1]Benchmark value obtained from gear weight approximation by RFCx.

[2]Benchmark value obtained from estimated cost of 2 sets of climbing gear.

Table 4.2: Phase 1 - Target Specifications

Metric No.	Need No.	Metric	Units	Value
1	-	Load (Device Weight)	lbs	~ 3
2	-	Installation Height (Target)	ft	60 - 70
3	-	Installation Height (Extreme)	ft	120
4	7	Installation time	min	36
5	12	Suitable tree identification	%	> 25
6	16	Safety	# of injuries	0
7	13	Closest branch	ft	200
8	18	Tree trunk diameter	inch	4 - 24
9	14	Sunlight	NA	Pass
10	15	Cellular signal	NA	Pass
11	-	Low Cost	$ USD	1800[1]
12	11	Transportable (Weight)	lbs/person	25[2]

Inherent Target Specifications (Metric 1 to 3)

The inherent requirements of the project are based on the fact that the current methods employed by RFCx are meeting their current needs - specifically the current method of climbing the tree meets the minimum targets of the project. This in part is what makes the current method suitable for benchmarking. As part of the boundaries on the scope of this project it was determined that the solution would not largely alter the working principles of RFCx's audio monitoring device (ie: a solar powered, audio monitoring, data streaming, up-recycled mobile phone), therefore it is assumed that the AMD will still require to be installed at the current operational heights of 60 to 70 feet, with extreme cases of up to 120 feet. The AMD's weight will also remain unaltered.

Time Improvement Target Specifications (Metric 4 and 5)

Values for the target specifications pertaining to the reduction in installation time, and the more general time reduction found through the improvement in the success rate of suitable tree identification, are set based on the customer statements detailing a concrete desire to improve these metrics - the stated desire in customer statement no. 6 in table 4.2 to decrease the installation time by 70% and the clear complaint in statement no. 11 that a 5 to 20 ratio of suitable trees identified to those inspected was not a satisfactory success rate.

Safety Target Specification (Metric 6)

A common metric utilized in industry to indicate safety is the number of recordable incidents. In the case of a non-profit NGO any incident can be catastrophic - either a partner is hurt and the project is shut down, or a founder is hurt and potentially out of commission. Therefore the only acceptable target is zero incidents.

Tree Variability Target Specifications (Metric 7 and 8)

Due to the variation in both the species of trees encountered and the general operating conditions of the different rainforests thatRFCx operate in, a preferable solution is one that is designed for a large range of conditions. The closest branch height of 200 feet was assigned based off first hand experience of RFCx, while the tree trunk diameters were estimates based on video and photo media of field operations made available by RFCx.

Device Operation Target Specification (Metric 9 and 10)

Cellar signal and sunlight are two core inherent requirements for the operation of monitoring device. Although both of these properties can be measure in applicable units - lux (lx) for sunlight and decibel-milliwatts (dBm) - this level of detail is not required for the specification of a solution at this time in the product development process. For RFCx's current purposes the issue of sunlight and cellular signal are considered pass or fail based on the ability to achieve 24 hour recording and streaming of data.

Cost Target Specification (Metric 11)

The requirement of the solution being low cost is an inherent need of the company - as a non-profit NGO funds are always bound to be a concern. The benchmarked value of $1800 USD should not be applied as a strict value. This is the value assigned for two sets of climbing gear and does not take into account the time required to train partners in its proper use. For most of the project, "low cost" would be applied as a more general goal, rather than limiting a solution concept to a hard cost value.

Weight Target Specification (Metric 12)

The weight value assigned to the transportable metric relates to the current weight estimate of the gear that RFCx is currently required to carry in the field - this includes climbing gear, ropes, AMD's, and the tools used for installation. Although it is an expressed wish of the customer to reduce the weight of the gear carried in the field, it does not signify that a superior solution with an increased weight would not be accepted as a suitable solution for their needs. Accordingly it should not be considered a hard value. The units of the metric is weight per person, thus allowing flexibility in the specification.

5 Search for Solutions: State of the Art

The search for solutions stage for the first iteration of the product development project is characterized by what is generally referred to as the SOA - determining the current state of available solutions and technology. The search for solutions consists of both an internal and external search; internal denoting ideas generated from the individual or development team's existing knowledge, and external relating to the opposite.

At this early stage of the project there is a greater focus on the external search; both to provide background information on the currently available technologies and because the implementation of ,"an existing solution is usually quicker and cheaper than developing a new solution."(Ulrich, 2003, pg. 124).

Throughout the search for solutions - and the entire project - concept classification trees were employed to record and organize solution paths. This allowed for the recognition of paths that were either over or under explored. Exerts from the classification trees are provided to guide the discussion on the search for solutions, with the full concept classification tree available in appendix 2.1. Concept classification trees are covered in greater detail in section 12.1.

5.1 Internal Search

The internal search is the use of creativity and ones personal knowledge to generate solutions. At this early stage of the project, where the state of the art has yet to be determined, the results of the internal search are utilized as a guide for the direction of the external search; along with how existing technologies may be adapted. At this time most new ideas require an external search to determine if such an idea has already been developed.

5.1.1 Kick-off Brainstorming Session

At the onset of the project, an initial brainstorming session was conducted to generate ideas prior to the deep dive of the external search of existing technologies. The results of this session would serve as the starting point for future explorations, both external and internal.

As the session was conducted at the very first stages of the project, the majority of the customer needs and requirements presented in section 4 were still under development and not available to the session participants. The question presented to the assembled group was the broad one of how to place and attach a mobile phone approximately 60 feet (18 meters) up a tree in a remote rainforest.

Participants of the initial brainstorming session were obtained from interested colleagues. While this may have limited the breadth of the represented technical expertise - the majority of participants were of a similar technical background - the diversity of personal backgrounds would ensure a broad range of ideas.

The goal of a brainstorm session is the generation of a large quantity of ideas. To support this endeavour it is important to suspend initial judgement of the ideas to avoid negatively effecting the creative process. The results of the brainstorm session are presented below in brief bereft of judgement.

Long pole

The utilization of a long pole to place and attach the device was inspired from one of the participant's experience on their family orchard. There they had experienced 10 meter long poles with pull cord operated shears attached to the pole end. Poles were available in both telescopic and sectional construction.

A quick internet search conducted at the time of the session revealed the availability of 35 foot (11.5 meter) long pole saws utilized for the pruning of tree branches. The inclusion of an attached chainsaw on the end of the pole added promise to the pole's utilization as a solution, as it represented a larger end load than an up-recycled mobile phone.

To provide ground support for such long poles, a loading dock inspired by oil field pipe shoes was envisioned.

Scissor lift

Scissor lifts are found throughout the construction and warehouse industry to provide an elevated work platform.

Ladders

The use of ladders to reach the installation point on the tree trunk.

Batclaw grappling hook

A grappling hook and personal ascender inspired by the comic book hero Batman. An anchor point is shot harpoon gun style from the ground into the installation point of the tree trunk. The installer is than pulled upward to the anchor point by a mechanical ascender.

Harpoon gun

A harpoon gun is used to shoot a harpoon into the tree trunk at the intended installation point. The harpoon is used as an anchor point to pull up and secure the AMD. The harpoon gun can be substituted for other fired projectiles - crossbow, dart gun, etc.

Drones

A drone is utilized to fly up to the installation point of the tree, while carrying the up-recycled mobile phone. A dart is shot from the drone, attaching the monitoring device to the tree trunk.

Air drop from plane

Devices are air dropped from planes into the canopy. Would require the redesign of the audio monitoring device.

Remote mechanical attachment of device

Methods for the attachment of the AMD to the tree trunk without the operator being present in the tree. Methods include mechanisms inspired by an impact driver, a nail gun, and a torque screwdriver.

GAS PRESSURE ATTACHMENT

Use of stored pressurized gas to attach the device to the tree. Inspiration from a BB gun's use of compressed air and CO2 canisters.

TRAIN A MONKEY

The training of a monkey to carry monitoring device up into the canopy for installation.

5.2 External Search

The external search at the product discovery phase of the project seeks solutions in comparable industries, with the hopes of finding a technology or best practice that can quickly be adapted to the problem at hand. As an added benefit, a more through knowledge of the current technologies also precipitates an enhanced comprehension of the customers needs and aids in future conversations.

Accordingly the external search began with a focus on directly comparable industries - primarily the arborist industry - to determine modern tree climbing practices, before expanding to industries unrelated to the manual climbing of trees.

Mind maps were maintained to track the results of the search for solutions - which would be latter converted into the concept classification trees highlighted in section 12.1. Exerts from the mind maps are provided for clarity throughout the section.

5.2.1 Arborist Industry

The arborist industry is concerned with the practice of arboriculture - which pertains to the care and maintenance of trees and other perennial woody plants. A large part of the industry is concerned with the climbing of trees for maintenance and removal purposes - a natural starting point for the determination of industry practices for the climbing of trees.

Techniques are divided by those that ascend the trunk of the tree directly, and those that implement the use of ropes for the ascent.

Tree Trunk Climbing Techniques

A collection of techniques designed to climb the trunk of the tree, or vertical pole, directly.

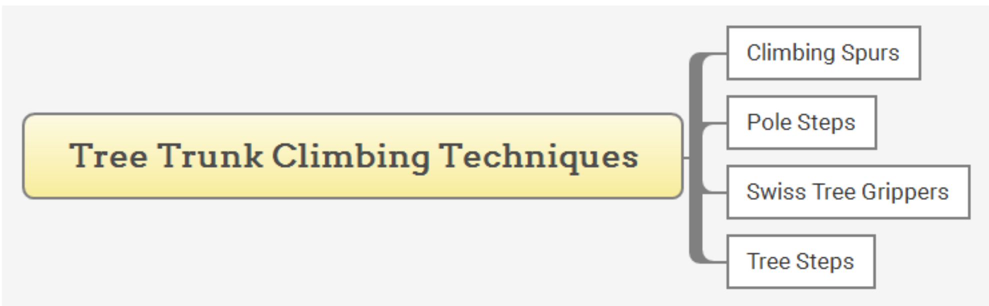


Figure 5.1: Concept classification tree - tree trunk climbing techniques

CLIMBING SPURS

Climbing spurs provide a fast and efficient method of accessing the crown of a tree by directly ascending the tree trunk. The system consists of climbing spurs - see figure 5.2 - and a lanyard (flipline) or a climbing line. The lanyard is kept horizontal during ascent, and is flipped up as the climber ascends by digging the spurs into the bole of the tree. This is a method akin to that utilized by telephone pole linesmen.

Despite its efficiency, Jeppson (2000, pg. 48) stresses that climbing spurs must only be used when the tree is to be removed, due to the potential for injury caused to the tree by the sharp gaffs - particularly on thin barked trees. Although the USDA Forest Service states that, “most thick-barked trees can be climbed repeatedly without serious harm to the bole.” (Davis, 2005, pg. 39).

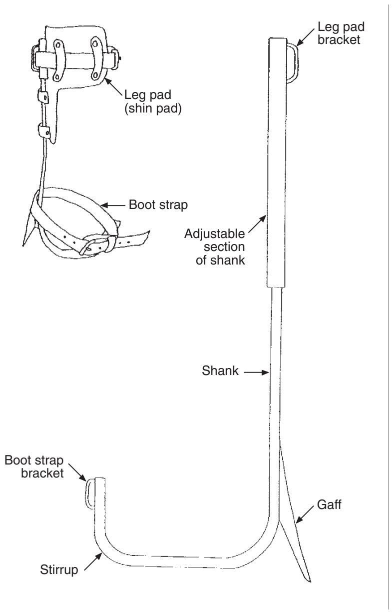


Figure 5.2: Climbing spurs (Davis, 2005, pg. 39)

POLE STEPS

Similar to those used on wooden utility poles, pole steps are screwed directly into the living bole of the tree. Only recommended for use by USDA Forest Service (Davis, 2005) when a tree will be climbed repeatedly over a number of years.

To be avoided due to permanent tree damage.

SWISS TREE GRIPPERS

Swiss Tree Grippers (Swiss Tree Climbers, Bicycles) are designed as a non-destructive alternative to climbing spurs. The set consists of two grippers that attach to the climbers feet, with metal bands that wrap around the trunk of the tree. The grippers are unable to by-pass limbs or other obstructions encountered along the tree trunk. A steel cable climbing belt is recommended for use with the Swiss Tree Grippers as the metal bands can cut through synthetic or natural fibre climbing belts. (Davis, 2005).

Swiss Tree Grippers can be used on tree trunks up to 26 inches in diameter. They can be difficult to use on small diameter trees, with separate bands required.

It is worth noting the high cost of the Swiss Tree Grippers, and that suppliers to the United States can be difficult to come by.

Figure 5.3: Swiss Tree Grippers (Forestry Suppliers, Inc., 2016)

TREE STEPS

Light weight metal platforms that are temporarily installed around the tree trunk. Available in a number of variations, they can be attached by chain, rope, or nylon webbing. Recommended to be used to bridge gaps between live branches, as they are inefficient for long ascents. For safety, a lanyard should be used at all times when using tree steps.

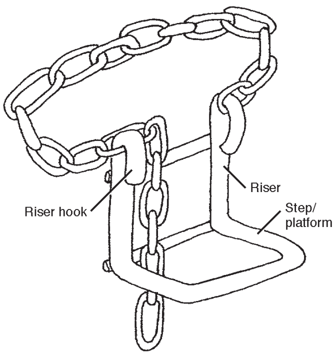


Figure 5.4: Tree step (Davis, 2005, pg. 55)

Rope Climbing Techniques

A multitude of ascent systems have been developed by arborists to gain access to the upper reaches of the trees they work on, almost as many variations in climbing systems as there are climbers to utilize them. These systems can be broadly categorized based on how the climbing line moves when the climber ascends; dynamic climbing line systems, where the rope moves with the climber; and static line systems, where the climber ascends a stationary line. The most popular dynamic systems fall under the Doubled Rope Technique (DdRT) - not to be confused with Double Rope Technique (DRT), which refers to the use of two separate anchor points - while static line systems are normally associated with Single Rope Technique (SRT).

The following sections will provide a top level overview of the two types of rope climbing systems, with some of the associated gear and techniques. It will not provide a list of the gear, knots, or all different systems available. An exert from the concept map is provided as a guide in figure 5.5.

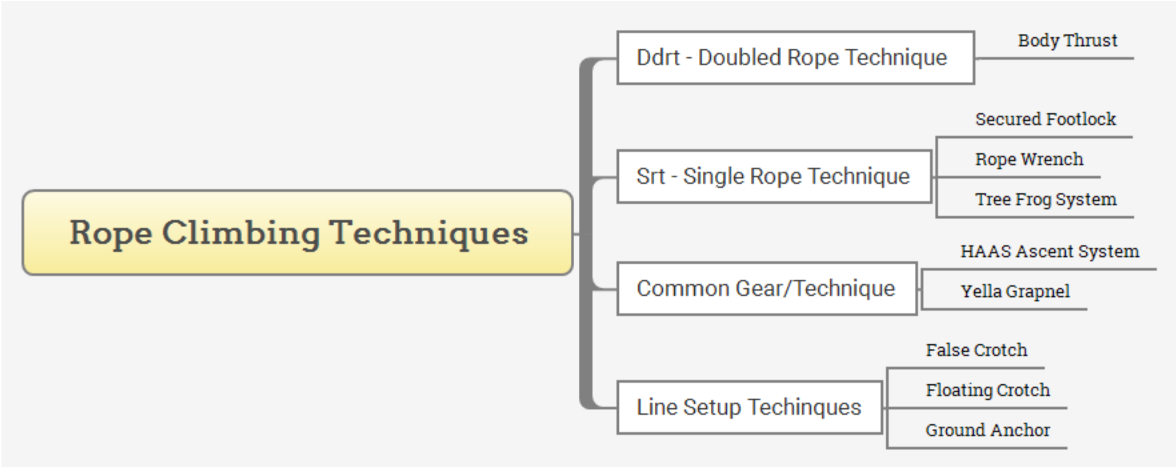


Figure 5.5: Concept classification tree - arborist rope climbing techniques

Doubled Rope Technique - DdRT

The double rope technique consists of a single climbing line doubled over the anchor point - typically a branch or tree crotch - with both legs of the rope descending parallel to ground level. The anchor point must be isolated, meaning that no other branches can fall between the two ends of the climbing line. DdRT can be further broken down to static and dynamic techniques. With static DdRT, both legs of the climbing line remain stationary as the climber ascends through a variety of techniques that can include mechanical ascenders or the secured footlocking technique. For dynamic DdRT, both legs of the line move while the climber ascends or descends. Body thrusting is a common technique utilized to ascend a dynamic DdRT system. (Adams, 2007).

Dynamic DdRT operates by creating a loop from the two ends of the climbing line, attached to the harness of the climber. As the climber raises themselves up the line, they take in the slack created in the loop by pulling the tail of the loop through a friction hitch. In this manner climber is able to perform a self belay. This loop nature of the line makes the system ideal for moving through the canopy, as slack can easily be added or removed from the system during a branch walk.

The DdRT system allows the climber to ascend the tree with the body thrust technique, described in the following section. This technique is of use when the line needs to be set close to the trunk of the tree to be ascended.

Additional advantages of the technique are that it requires a minimum amount of gear, with only a climbing harness, ropes, and a knowledge of the proper climbing knots required for the most minimal setup. This allows an entire set of climbing gear to be packed into a standard backpack (Kilgore et al., 2008, pg. 1318).

The disadvantages include the need to isolate the anchor branch and the increased friction at the anchor point due to the dynamic nature of the climbing line. Its 2:1 climbing ratio due to the contraction of the loop during ascent make it less efficient for long climbs than a static line system. In general the DdRT system requires more physical strength from the climber than the SRT system.

DdRT was the preferred method of canopy access for the University of Central Missouri to prepare their students for tree canopy field research. Students were taught over a two-day tree climbing school. Highlighting the safety of the the technique, over the eight year duration reported on, more than 500 individual trees were climbed by 20 students without injury. 49 tree species were climbed, usually exceeding 60 cm trunk diameter at breast height, and greater than 30 meters in height (Kilgore et al., 2008).

Body Thrust Technique

The body thrust technique is a common, basic technique utilized with a dynamic climbing line system. It is most often used when the climbing line is installed close or against the tree trunk.

Performance of the technique is depicted in figure 5.6. First, the climber is clipped into a DdRT system. Once off the ground, the climber places both feet high on the tree trunk and thrusts their hips forward while simultaneously pulling on the tail of the rope just below the friction hitch. The friction hitch is quickly slide forward by the climber to take up the slack in the rope. These motions are repeated, as the climber walks up the trunk of the tree. (Jepson, 2000, pg. 40).

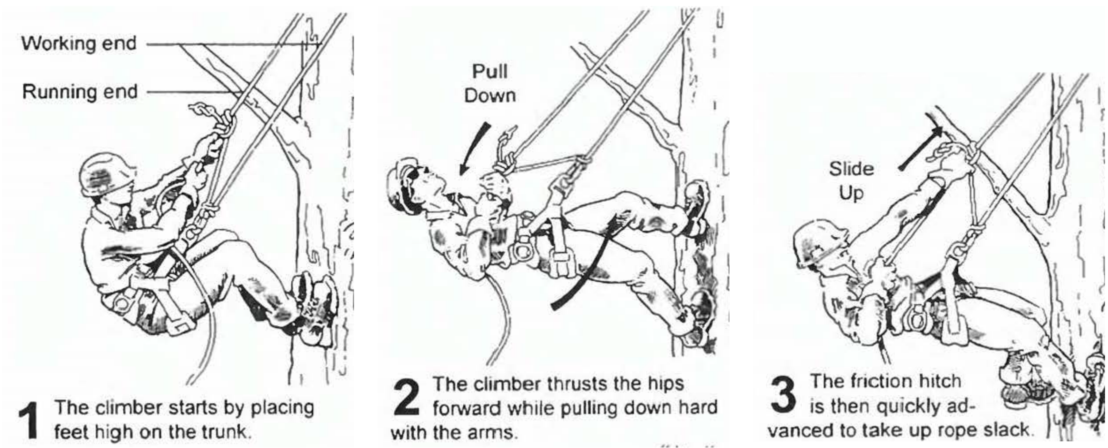


Figure 5.6: Body thrust technique on a DdRT system (Jepson, 2000, pg. 40)

SINGLE ROPE TECHNIQUE - SRT

The single rope technique consists of a single rope placed over the anchor point. One leg of the line hangs where it can be accessed by the climber. The second leg may be run to the ground and secured on the ground by a number of means - such as anchored to a tree trunk - or the second leg may be secured in the canopy at the anchor point. (Adams, 2007). The line is then ascended through a number of techniques, ranging from the gear minimalistic secured footlock to a variety of systems that take advantage of mechanical ascenders.

The SRT is considered by Jeppson (2000) to be “hard to beat when the climb is long or when the rope cannot be isolated around a single limb,” both of which apply to RFCx’s experiences in the field.

The preference shown for long climbs is due to the greater efficiency of the technique compared to DdRT systems. Part of this is due to SRT’s use of the climbers legs to power

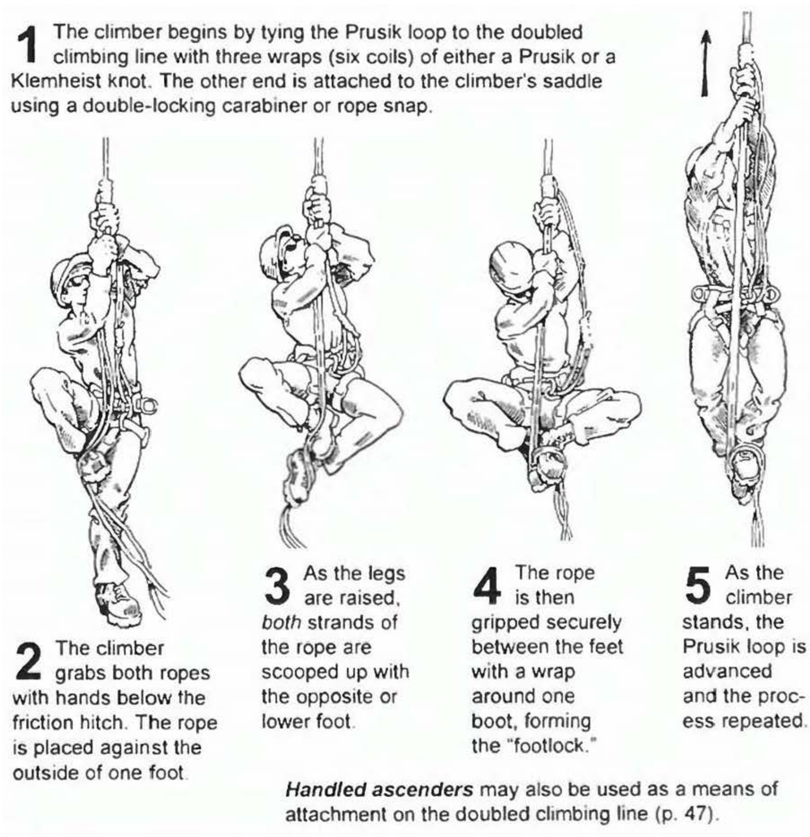


Figure 5.7: Secured footlock technique (Jepson, 2000, pg.'42)

their assent, a much larger muscle group compared to the climber's arms in the body thrust method. The other part is due to the static line providing a 1:1 ratio on the rope pulled to height climbed, compared to the 2:1 ratio present in the dynamic DdRT systems.

Secured Footlock

The secured footlock technique is often selected when the climbing line is away from the tree trunk, as bumping into the tree trunk can hinder the process. At its most minimal approach, the climber utilizes a friction hitch - typically a Prusik loop - around the climbing line. Mechanical hand ascenders can also be incorporated to aid the climber. The steps required to perform the technique are outlined in fig 5.7. The technique can be preformed on both a doubled line, as depicted in the figure, or on a single line.

The secured footlock is considered by many in the industry to be one of the hardest techniques to master, but once mastered it can provide quick access to the canopy. The ISA tree climbing championships require a competitor to complete a 15 meter climb in 60 seconds in order to simply qualify for regional competition. The world record for such a climb has was set at 14.11 seconds in 2011. (ITCC Rules Committee, 2015).

Rope Wrench

A previous limitation of SRT was the need to perform a changeover when a climber wished to descend the line - a potential safety hazard if one needs to descend quickly to avoid a hazard encountered while climbing, such as insects. The Rope Wrench from Singing Tree forms a bend in the single rope that allows it to dissipate friction and the associated heat from the climber's friction hitch. Without such a device the generated heat would melt the cord of the friction hitch.

Figure 5.8: Singing Tree Rope Wrench (Treestuff, 2015c)

Tree Frog System

Due to the difficulty in mastering the secured footlock technique a number of systems utilizing mechanical ascenders have been designed to take advantage of the larger muscle group of the climber's legs. The Tree Frog system is one such design.

Designed by Sherrilltree for climbs exceeding 60 feet, the system consists of a hand ascender, a chest ascender, a foot ascender, and a foot loop for the foot free of the foot ascender. The setup allows the climber to make small stepping motions to walk up a static single line.

Figure 5.9: Sherrilltree Tree Frog system (Sherrilltree, 2015b)

Common Gear

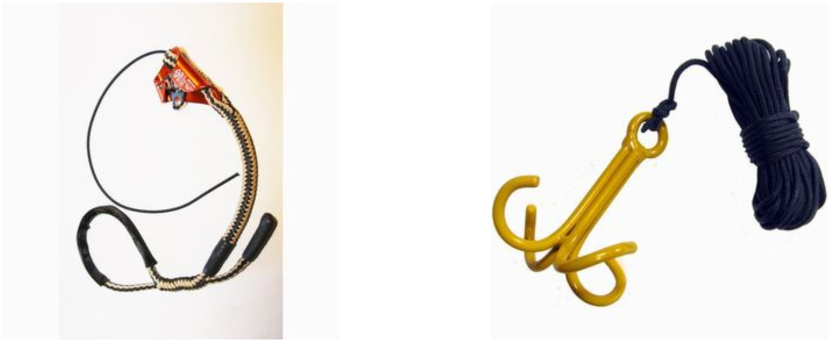
The section contains just a few of the pieces of tree climbing gear that can be added to aid a climber of a DdRT or SRT system.

HAAS Ascent System

The HAAS ascent system is a fairly new piece of tree climbing equipment designed by Micheal Frankhauser of Ohio. In the past a climber was only able to utilize a single foot ascender due to space constraints on the rope. Through the clever use of tethered bungee cord, the HAAS system allows a climber to utilize the energy of the other foot, essentially performing the role of a second foot ascender.

Yella Grapnel

A simple grapnel with 20 feet of attached throwline. Utilized to make traverse horizontally when on the climbing line, or to retrieve objects from afar. Recommended by members of the Finnish Tee Care Association (SPY) when discussing RFCx's issue of having to re-climb trees due to not being close enough to the tree trunk for installations upon decent.



(a) HAAS ascent system (Treestuff, 2015b)

(b) Yella Grapnel (Treestuff, 2015d)

Figure 5.10: Common tree climbing gear

LINE SETUP TECHNIQUES

A review of a few different methods of setting up climbing lines for additional system flexibility and safety.

False Crotch

A false crotch is a broad term used to define an artificial anchor point installed in a tree in place of using a naturally occurring tree crotch or branch. False crotches can consist of a nylon webbing wrapped directly around the tree trunk or an existing crotch as shown in figure 5.11.

An alternative setup proposed by Daniel Holliday of climbingarborist.com is essentially a static line setup for SRT, with a pulley attached to the elevated end by a carabiner. A second

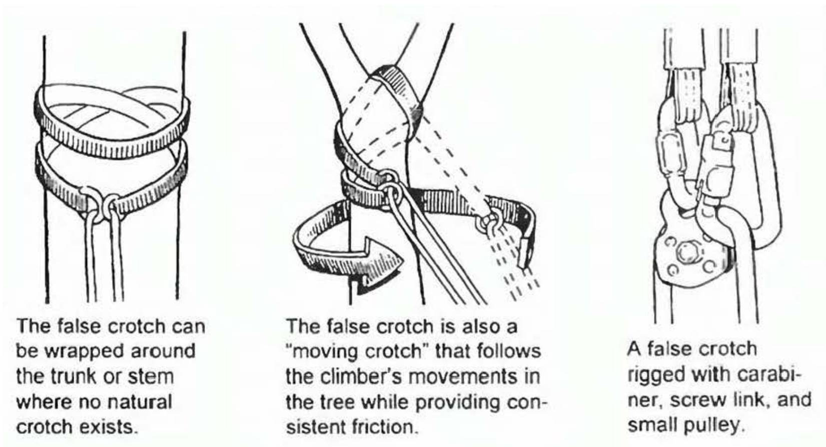


Figure 5.11: False crotch (Jepson, 2000, pg. 27)

line is then run through the pulley with both ends descending to the ground. (Holliday, 2012b). The second line can then be setup for either DdRT or SRT, though such a setup provides greater additional value to a DdRT system.

When combined with a DdRT system it produces a frictionless system - reducing friction wear on both the tree and the rope - while providing a ground lower-able system for added safety. The need for branch isolation is also eliminated, a complaint voiced by RFCx. While a SRT system already possesses many of these benefits, the false crotch can still provide value when installed directly to the tree trunk in the case when a suitable crotch or branch is unavailable.

Floating Crotch

A floating crotch adds a moveable anchor point to either a doubled rope or a single rope system through the use of a friction hitch tied to the single or doubled line. A DdRT system would typically be attached to the floating crotch point. This allows the climber to ascend with the secured footlock method, as described in 5.2.1, on a doubled rope setup or with a standard SRT ascent method on a single rope setup. The added functionality is found when a DdRT system is attached to the floating anchor point. This allows the climber to quickly alternate from their efficient ascent method to a standard DdRT system for increased lateral mobility in the tree canopy.

When the floating crotch is installed on single rope system, it allows for the climber to be belayed by ground staff in the case of an emergency. (Holliday, 2012c).

Ground Anchor

A standard feature of SRT systems is the inclusion of a ground anchor, which is simply the non-climbed end of the line being affixed to a ground level anchor point - commonly the trunk of a tree. With the use of belay device, such as a figure eight device, a ground team member is able to lower the climber to the ground in the case of an emergency.

Line Placement

Before any of the previously described rope climbing techniques can be utilized to gain access to the upper reaches of a tree, the climbing rope must first be installed. The standard method is to first set a lightweight throwline over the anchor point, attach one end to the climbing rope, and raise the rope into the tree by pulling on the other end of the throwline. The following section will review some of the ways of setting the initial line.

Throwline and Throwbag

The classic tools of tree climbers, the throwline and bag combination allows for accurate shots of 60 to 70 feet (21 to 24 meters). The setting of the throwline is the first step in installing a rope climbing system, whether the following step be a climbing line or false crotch.

Throwlines are selected based on their construction, weight, strength, and surface friction. Typical lines are 1/8 inch in diameter, and can weight as little as 2.1 grams per meter. (Jepson, 2000).

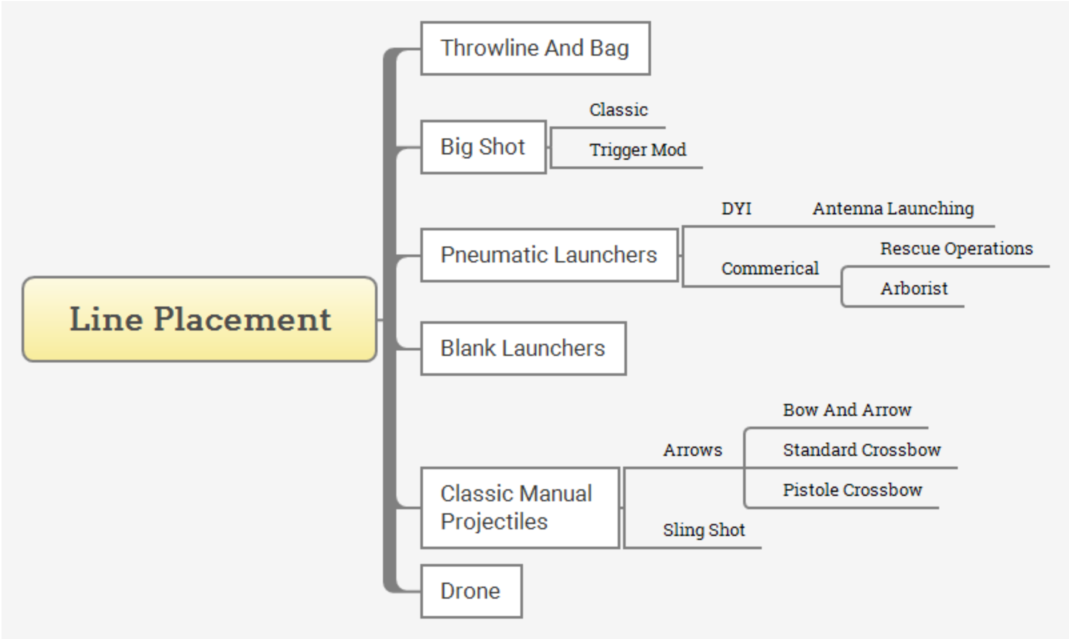


Figure 5.12: Concept classification tree - line placement

The throwline is stored in a weighted pouch - the throwbag - ranging from 12 to 20 ounces (340 to 570 grams). Throwbags and lines can be launched through a variety of means; multiple hand-thrown techniques and numerous aided techniques. As the rainforest environments where RFCx operate can require lines to be set at 120 feet (36.4 meters), the remainder of this section will focus on assisted launch techniques.

Big Shot

The Big Shot is a large, manual sling shot specifically designed for throw bags developed by Sherrilltree. Designed to penetrate dense canopies with accuracy, the Big Shot is advertised to launch throw weight up to 150 vertical feet (45.5 meters) (Sherrilltree, 2015a). For higher elevations and increased power, an additional segment an be added to extend the base of the Big Shot.

Big Shot Modification

Despite its widespread use throughout the arborist industry, the Big Shot is not without its criticisms. Designed to be utilized by a single operator, it can be difficult to simultaneously hold the sling back and aim, especially when requiring the maximum height range and a high level of accuracy - as in the case of RFCxS.

Simple modifications to the Big Shot can help overcome some of its short comings. Presented by Daniel Holliday of climbingarborist.com, his Big Shot modification adds a series of pulleys and the addition of an archery trigger to separate the tasks of holding the sling back in the firing position, aiming the sling, and firing. The pulleys are utilized to draw the sling back, while the archery trigger is used as the release mechanism, thereby freeing the operator to aim the Big Shot as his leisure.

The cost of such a modification has been worked out to fall in the \$43 to \$63 United States

Dollars (USD).

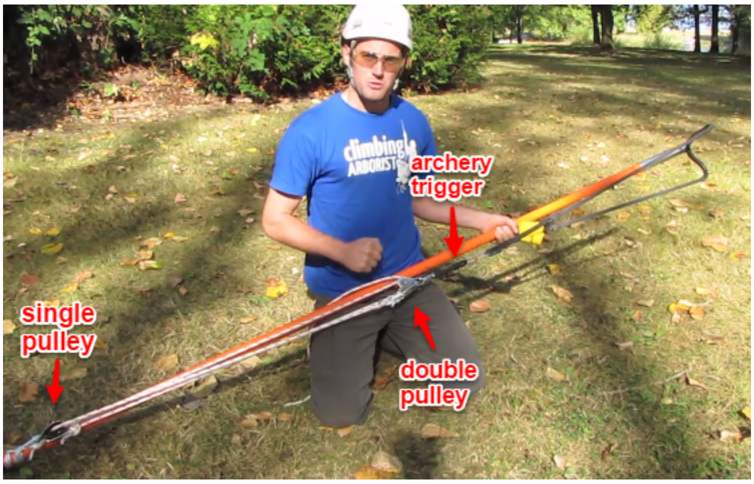


Figure 5.13: Big Shot with modifications (Holliday, 2012a)

Pneumatic Launchers

Pneumatic launchers utilize air pressure to propel a projectile at great velocity and range. They have been developed at the Do It Yourself (DIY) and commercial level.

DIY Antenna Launcher

A group of antenna hobbyists have developed and published designs for /acDIY pneumatic tennis ball launchers. Constructed from common hardware material of PVC piping, sprinkler valves, and pressure gauges ; these designs match the DIY attitude displayed by RFCx to date. As a safety measure the launchers utilize tennis balls for projectiles.

Figure 5.14: CSV19 pneumatic DIY antenna launcher (Alan Biocca Engineering, 2015)

The CSV19 launcher has a maximum range of 200 feet (60 meters) when pressurized to 80 pounds per square inch (psi), weighs approximately 6.5 pounds, and has an overall length of 19 inches. Kits are available for $139 USD.

The simple addition of a hand held bike pump would allow for the launcher to be recharged on location.

Commercial Launchers

Commercial line launchers are available for both the arborist industry and the search and rescue industry.

For the arborist industry, Tree Stuff has developed their own simple pneumatic launcher, the APTA. Built with a butterfly valve as the trigger connecting a pressurized chamber and the barrel, it is quite likely that better results are obtained from the sprinkler valve utilized in the CSV19. The APTA is advertised as being able to set lines at heights greater than 100 feet (30 m). It weighs less than 7.5 pounds and costs $200 USD.

For the search and rescue industry, Rescue Solutions International has developed the ResQmax - a pneumatic launcher charged at a pressure of 3000 psi with a vertical launch height of 110 feet (33 meters) when equipped with a grappling hook. Rescue Solutions international also offer a tactical version that operates at a pressure of 3000 to 4500 psi, with a vertical launch height of 200 feet (60 meters). The launchers weigh 3.4 pounds and 4.4 pounds respectively. The rescue version is available at a cost of $2,218 USD.

(a) APTA (Treestuff, 2015a)

(b) ResQmax (Rescue Solutions International, 2015)

Figure 5.15: Commercial pneumatic line launchers

BLANK LAUNCHERS

An alternative to the pneumatic launchers and the Big Shot, line launchers powered by .22 calibre blanks are available for the setting of lines. Capable of reaching heights of 120 feet (36 meters) and higher. Once set, the placed line is retrieved via the attached reel.

Firing range is controlled by the power of the .22 calibre blank selected, and is available in ranges of 40 feet, 80 feet, and 120 feet. The launcher is not considered a firearm - although the transport of blanks could cause difficulties when travelling through airports.

The launcher weighs 3.3 pounds and is available at a cost of $237.99 USD.

CLASSIC MANUAL PROJECTILES

Classic manual fired projectiles have also been utilized to set throwlines. The addition of a reel for the storage and retrieval of the throwline is a common addition to classic bows, crossbows, and sling shots.

Safety becomes a main concern with such projectiles. Even with a blunted tip, an arrow,

Figure 5.16: Line launcher - blanks (Specaialty Products Co., 2015)

crossbow bolt, or lead sinker descending from over 150 feet (45.5 meters) is a significant hazard. There is also the potential of harm to the inhabitants of the canopy.

DRONE

Drones, specifically hex-copters, present an attractive alternative for line setting. If one could fly around an anchor point and return to ground level without incident, it is reasonable to expect an increase in the accuracy of line placement.

Drones are covered in more detail in section 5.2.6.

Power Ascenders

Power ascenders referees to mechanical personal ascenders that have been designed for working at height. They are used as a personal elevator that climb standard ropes. The majority of power ascender available today are for the commercial rope access industry, while in the past there were some designs developed by sport enthusiasts.

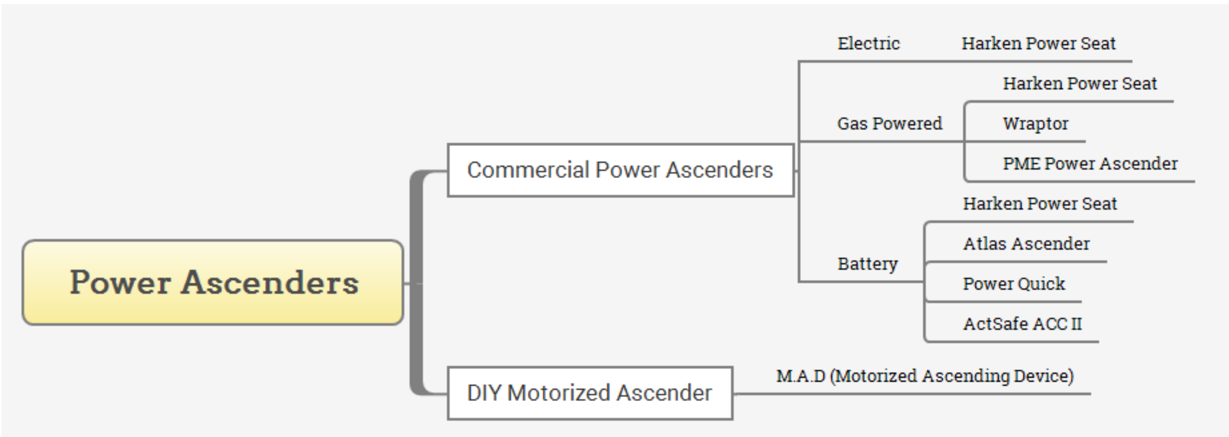


Figure 5.17: Concept classification tree - power ascenders

COMMERCIAL POWER ASCENDERS

Commercial power ascenders have been designed for the at height inspection and maintenance industry (wind turbines, bridges, towers) and the search and rescue industry. Very few models have been designed specifically with the arborist industry in mind.

While all models allow for the operator to be pulled up the line, a few allow the operator to sit on the ascender as a chair and ride the ascender up. Most models also function as a ground winch.

Power ascenders are available in gas, electric, and battery powered models. Prices range from $2,500 to $10,000 USD.

RopeTek Wraptor

The Wraptor by RopeTek is a gas powered ascender designed specifically with the arborist industry in mind. It utilizes a two-stroke, gasoline powered engine to achieve ascent speeds of 100 feet per minute, with a lift capacity of 300 pounds. It has a range of 1000 feet on a single tank of gas and retails for $2500 USD. The Wraptor weighs 23 pounds.

Figure 5.18: Power ascendor - RopeTek Wraptor (RopeTek, 2015)

DIY Motorized Ascender

The Motorized Ascending Device (MAD) is a motorized ascender developed by Nevin Davis in the 1971 for the DIY spelunking enthusiast. Mr. Davis published his design and the instructions for its construction to the public in 1985.

Utilizing a single horsepower two stroke engine, the MAD is able to handle loads of 400 pounds and weighs 23 pounds. In 1971 the cost of the parts to construct the MAD was $120 acUSD, far cheaper than the comparable, commercial Wraptor.

Figure 5.19: Use of MAD in ascending (Davis, 1984)

Ground Winch

Portable ground winches are used in the arborist industry to aid in the felling of trees and the hauling of gear up into the canopy of the tree. Designed for higher operating loads than power ascenders, they represent an increase in power and weight.

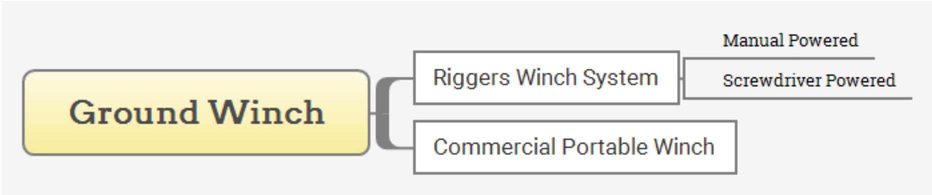


Figure 5.20: Concept classification tree - ground winch

A manual winch system was explored after a recommendation by a new business manager at Hacken, whose PowerSeat power ascender is able to double as a ground winch. He also suggested the use of the PowerSeat as a ground winch to raise a climber up the line - similar to the method described with a riggers winch in the following section.

A ground winch system of raising and lowering the climber allows for the climber to be lowered by a ground team member, similar to methods described under ground anchors in section 5.2.1. This is an added safety feature of such a system.

RIGGERS WINCH SYSTEM

Sean Cogan suggested the setup for tree canopy access depicted in figure 5.21b. A new business manager at Harken, his background includes Society of Professional Rope Access Technicians (SPRAT) L3 certification and has experience in setting up ziplines in the forests of Belize.

The system consists of a false crotch (see section 5.2.1) with a pulley attached to the elevated end, as depicted by the red line. This line is anchored to the base of the tree, as in an SRT system described in section 5.2.1. A riggers winch, designed for the yachting industry, is secured to the base of the tree. A second line, depicted by the orange line in fig 5.21b, is run through the pulley at the end of the false crotch. One end is attached to the climber, while the other is run through the riggers winch. The climber is raised into the tree canopy by operation of the riggers winch, which can be manually operated or driven by a drill.

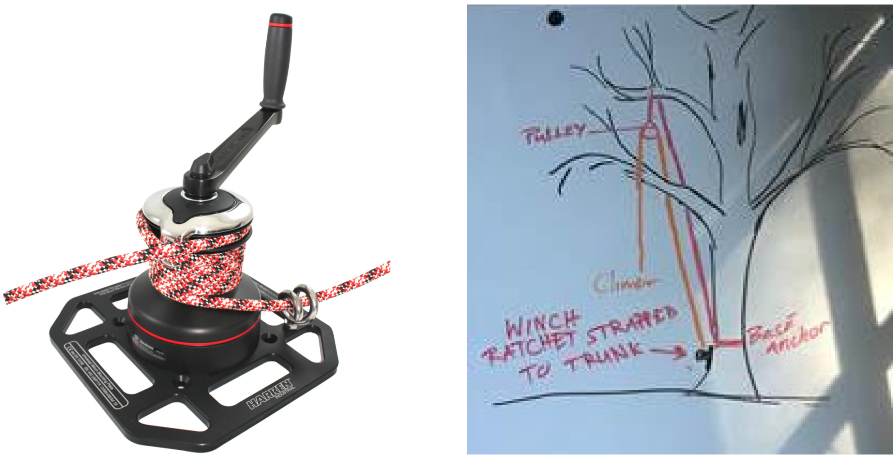
Cogan recommend the use of Harken's Riggers Winch 500.

5.2.2 Biologist Techniques

For years biologists have been experimenting with a number of ways to collect samples from the rainforest canopy. Before the adoption of modern climbing techniques described above, the intrepid researcher was left to turn to locals and even trained monkeys to climb up into the canopy and retrieve biological samples. In their heyday, when funding was readily available, they would look to canopy cranes and dirigibles to gain access to the ecosystem contained within the forest's branches. (Butler, 2012).

5.2.3 Installation/Work Platforms

A collection of industry equipment utilized to gain access and provide an operating platform for work at above ground elevations. As all of these methods would require a road for transportation - either self powered or, in the case of the portable lattice towers, on a flatbed truck - they can already be deemed unsuitable. Therefore they will not be described in further detail.



(a) Harken's Riggers Winch 500 (Harken Industrial, 2015)

(b) Riggers winch setup supplied by Sean Cogan (Cogan, 2015)

Figure 5.21: Riggers Winch System

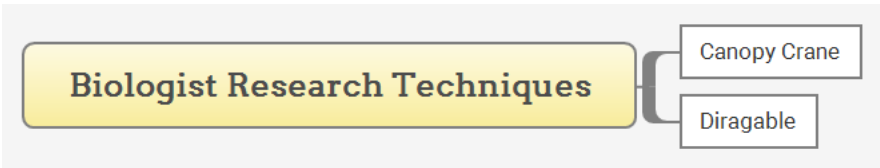


Figure 5.22: Concept classification tree - biologist research techniques

5.2.4 Military Rapid Access

Military equipment designed for the rapid access of elevated positions, such as ship decks and the roof of buildings. Includes grappling hook launchers, extendable poles, batman inspired mechanical ascenders, and simple rope ladders.

As the line launchers and power ascenders are essentially military grade versions of the ResQmax pneumatic launcher described in section 5.2.1 and the power ascenders described in section 5.2.1, they will not be detailed in this report.

Pneumatic Poles

Pneumatic powered extension poles have been developed for military operations. Primarily designed to deliver a grappling hook with a rope ladder, the end of the pole can also be fitted with an antenna or camera. During operation a reservoir of compressed air fills the segments of the telescopic pole, silently extending the pole. The pole will slowly loose pressure over time, fully retracting over a couple of hours.

Poles are available in 30, 40, and 50 foot (9, 12, and 15 meter) lengths, with customizable lengths available. Due to the extending nature of the poles, they are able to be stopped at any intermittent length.

The 15 meter version weighs 24.7 pounds (11.2 kilograms (kgs)), with a fully charged reservoir adding 35.4 pounds (16.1 kgs).

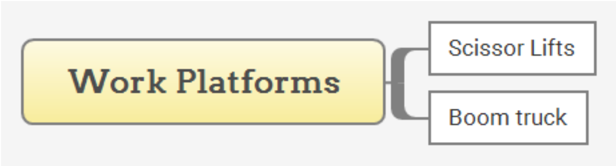


Figure 5.23: Concept classification tree - work platforms

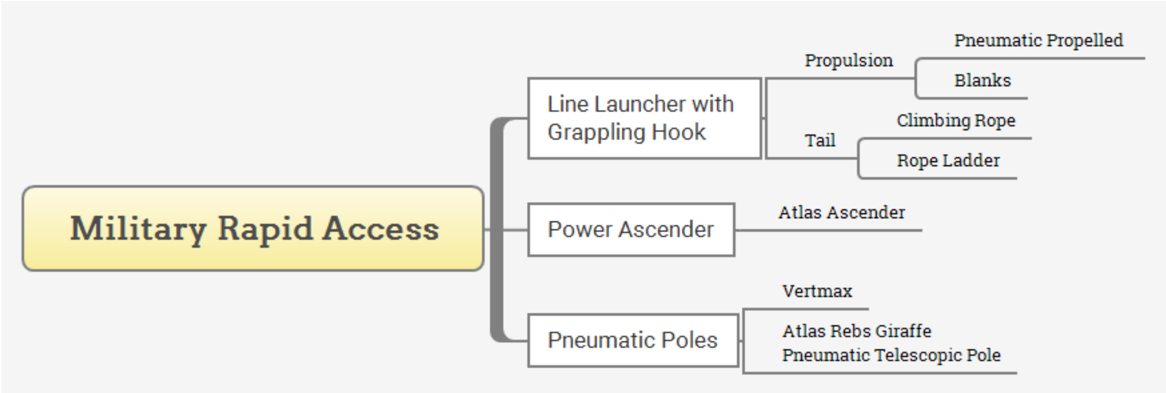


Figure 5.24: Concept classification tree - military rapid access

The weight of the supply payload (ladder and grappling hook) equal 8.4 pounds (3.8 kgs). This validates that such a pole could support RFCx's monitoring device.

Figure 5.25: Vertmax pneumatic pole by ResQmax (Recue Solutions International, 2013).

5.2.5 Robots

A collection of robots and machines designed to climb vertical surfaces. It is worth noting that none of the technologies researched for this section are commercially available.

Treebot

Treebot is an autonomous tree climbing robot developed at the Chinese University of Hong Kong. Resembling an inchworm, the robot utilizes a pair of omni-directional tree grippers that allow Treebot to climb a wide variety of tree trunk surfaces, diameters, and angles. While only weighing 1.32 pounds (600 grams), it has a payload capacity of 3.85 pounds (1.75 kgs). (Lam and Xu, 2011).

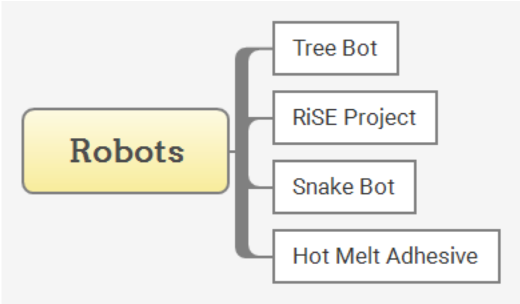


Figure 5.26: Concept classification tree - robots

RiSE project

The RiSE project seeks to create bio-inspired climbing robots.

The RiSE V3 is a four legged climbing machine developed by Boston Dynamics that is able to achieve climbing speeds of 21 cm/s on a wooden telephone pole, and has demonstrated the capability of climbing natural trees. It has a mass of 11.9 pounds (5.4 kgs) and a length of 70 cm.

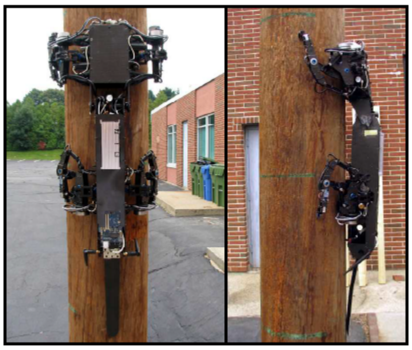


Fig. 1: Dorsal and lateral views of the RiSE Version 3 climbing robot. Four powerful legs, each with two actuators, grip a wooden telephone pole using claw-like appendages.

Figure 5.27: RiSE (Haynes et al., 2009)

Snakebot

The Snakebots developed by the Biorobotics Lab of Carnegie Mellon University are designed with many internal degrees of freedom. This allows them to achieve behaviours akin to swimming, climbing, and crawling. By constricting around a tree trunk, they are able to roll themselves upward.

Hot Melt Adhesive Robot

This robot utilizes Hot Melt Adhesion (HMA) to glue itself to the climbing surface. Similar in principle to a glue gun, HMA is solid until heated, at which point it transforms to a liquid state. As the the HMA cools it returns to the solid state. This allows for passive support of the robot and any attached payload. The robot is outfitted with servo motors and thermal control units to actively vary the temperature of the adhesive, as it will need to reheat the HMA to detach a leg from the climbing surface and travel onward.

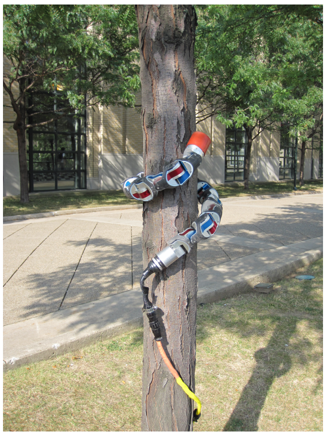


Figure 5.28: Snakebot climbing a tree (Biorobotics Lab, 2013)

Due to the large breaking tension and bonding strength of the HMA investigated, a relatively small climbing robot is able to support large payloads. (Osswald and Iida, 2011).

5.2.6 Drones

Unmanned Aircraft Systems (UAS), Unmanned Aerial Vehicles (UAV), or drones as they are commonly referenced have been covered extensively in the media as an upcoming conservation tool. While drones are expected to take a greater role in wildlife conservation efforts world wide, it is important to understand the types of drones and their capabilities, as the reported successes of military grade drones have not always translated to civil efforts with lower cost and less robust models. That being sad drones do provide an interesting tool that is becoming more accessible to the public. (Tenenbaum, 2015).

For the purposes of RFCx current goals drones have the potential to aid in device installation, line setting, and reconnaissance.

Drones can generally be grouped into two categories based on their mode of flight; fixed wing and multi-rotor.

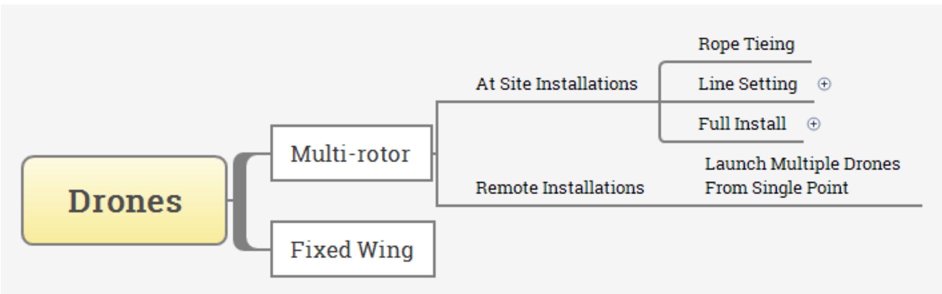


Figure 5.29: Concept classification tree - drones

Multi-rotor

Multi-rotor drones include any drone that is elevated by more than a single rotor; common varieties include quad and hex-copters. These types of drones allow for direct vertical ascension. This capability lends itself to the exploration of direct installations, line setting, and rope tying.

DIRECT INSTALLATIONS

The design of a drone to raise the audio monitoring device and attach it to the tree remotely. Would require the custom design and construction of a purpose built system.

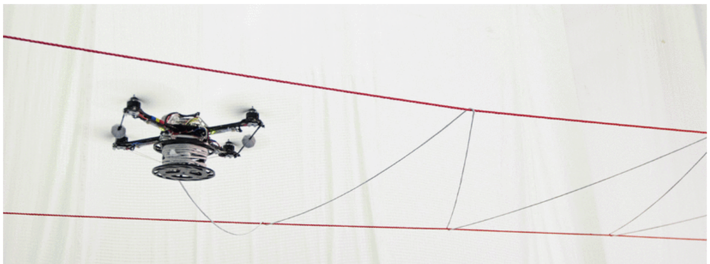
LINE SETTING

The use of a hex-copter to fly up a climbing throwline, as described in section 5.2.1, over a suitable tree branch or crotch and return to the operator. With 200 feet of throwline available at a weight of 363 grams, there are vast multitude of off the shelf drones available - although care must be taken to take into account the operation environment of the rainforest if selecting a drone. Factors such as temperature, humidity, air turbulence, and shielding of the rotors from falling objects must be taken into account.

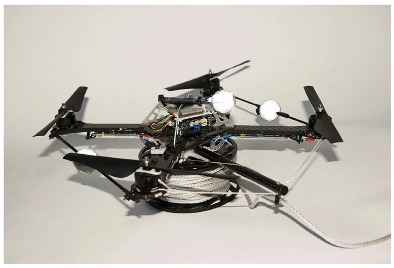
ROPE TYING

Work in aerial construction is being conducted at ETH Zurich in their Flying Machine Arena. Research on the aerial assembly of tensile structures with autonomous quad-copters has produced a rope bridge that can bear the weight of an individual. The UASs are equipped with a motorized spool that allows for control over the tension acting on the line during deployment and provide a good working example of what could be possible in the field.

As part of the research they have developed the capability to tie knots with their flying machines. Specifically they have demonstrated the ability to tie a munter hitch in the controlled environment of the Flying Machine Arena, a common knot in climbing (Augugliaro et al., 2015).



(a) Quadcopter constructing a rope structure



(b) Quadcopter equipped with passive roller to deploy rope

Figure 5.30: Quadcopter for aerial construction (Augugliaro et al., 2013)

Fixed Wing

With their long range and ability to host a wide range of sensors, fixed wing drones can be utilized for autonomous or remotely piloted reconnaissance, mapping, surveying, and monitoring of animals. Examples in industry include palm oil producer Cargill deployment of UAVs to map the forests where they operate to ensure compliance with their zero deforestation policy (Butler, 2014).

5.2.7 Yard-work Equipment

During the initial brainstorm session described in section 5.1.1, long poles employed in the orchard industry were suggested as a possible installation route. A number of companies

Figure 5.31: Fixed wing drone taking off (Mulero-Pázmány et al., 2014)

produce long pole saws for the trimming of tree branches from the ground. End of pole tools saws included gas and electric powered miniature chainsaws, pull chord operated cutters, or simple blades that require the downward motion of the entire pole to saw; as displayed from left to right in figure 5.32b.

Add-a-pole was contacted after their 35 foot (10.5 meter) motorized polesaw prompted a general inquiry into how long a pole they were able to supply. The recommended height with a 3 pound end weight was 50 feet (15 meters). It was further advised that stability of pole would be lost at heights exceeding the 50 foot mark.

The pole is a sectional pole made up of 6 foot (1.8 meter) lengths of 1.75 inch diameter aluminium poles. Each pole weighs 2 pounds (900 grams). The entire pole would cost $300 USD. (Hill, 2016).

(a) Extended add-a-pole   (b) End attachments for add-a-pole

Figure 5.32: Add-a-pole (Add-A-Pole, 2016)

5.2.8 Indigenous People

Research verified that some people indigenous to the rainforest do have a culture and tradition of tree climbing - with some beginning to climb trees from the time they can walk. Such observed techniques were either by hand or utilizing rope in a manner similar to a linemen's belt.

As RFCx's local partners to date have not possessed a tree climbing tradition, and as the techniques are not adaptable in a safe manner, this search track was terminated early.

6 Results: Early Recommendations

The technology and techniques uncovered in the state of the art phase of the search for solutions resulted in an increased understanding of the challenges associated with the current installation method and allowed for the identification of promising paths forward for the improvement of the installation process.

Presented technologies are divided into methods available for immediate implementation to improve operations on the ground, and those that warranted further exploration and development. Determination of which paths to pursue are based on the reaction of the customer to the presented results that are discussed in section 7.

6.1 Immediate Improvements

The state of the art exploration provided a number of options for the immediate improvement to the tree climbing operations being conducted by RFCx in the field. Key among them are the adoption of up-to-date industry rope climbing techniques, the addition of mechanical ascenders, and changes to methods of line setting.

Climbing Method Recommendations

With a new understanding of the climbing techniques employed by the professional tree climbing industry, a number recommendations to immediately improve the climbing methods employed by RFCx in the installation of AMDs could be made. These recommendations include a switch to an SRT system (if not already being employed), along with the adoption of additional gear and system setup techniques.

SRT for climbing

Based on the information on the current climbing technique supplied by RFCx through video and verbal communication, and the knowledge of the climbing techniques presented in section 5.2.1, the climbing technique being employed was initially identified as a doubled rope technique. This was supported by a climbing video provided by RFCx depicting a kicking motion against the trunk of the tree that resembled the body thrust technique, as described in section 5.2.1, along with their partner Tree Monkey Fun advertising the DdRT technique for teaching (it is worth noting that at this time RFCx had not clearly identified the climbing technique being employed). As outlined in section 5.2.1, this is a far less efficient method for long ascents. Therefore the switch to a single rope method is recommended at this time of the project.

False crotch for DdRT

The switch to an SRT system would also have the benefit of eliminating the need for branch isolationism during line setup, thus improving the time required to set up the climbing system in the field. If an DdRT climbing system is to be employed, it is recommended that the false crotch outlined in section 5.2.1 be utilized for the line setup, as this would also eliminate the need for branch isolation. An additional benefit would be the facilitation of a ground anchor setup for the DdRT system.

Ground anchor

It is recommended that if tree climbing is to continue, that a ground anchor system be employed to allow for the climber to be lowered by a ground team member in the case of an emergency, as outlined in section 5.2.1. No modification to the SRT system would be required to incorporate a ground anchor.

Tree frog system

Conversations were held with professional arborist Daniel Holliday to obtain his expert opinion on tree climbing technique recommendations. During the discourse he viewed the video of RFCx's current climbing method. With the new information provided by RFCxat this time of their use of foot and hand ascenders (jumars), Daniel identified that they were in fact employing an outdated SRT technique. He recommended the use of the tree frog system, as outlined in section 5.2.1, as in his opinion the older SRT method is, "no way near as efficient as the frog walker system." With the tree frog system an ascent of 50 to 60 feet (15 to 18 meters) should require 3 to 10 minutes, depending on the skill and physical condition of the climber. (Holliday, 2015).

Secured footlock

It is further recommended that the secure footlock method detailed in section 5.2.1 not be adopted as the primary rope ascent technique, due to the high level of skill and experience required. Despite this it would remain a useful backup technique in instances where gear has become lost or inoperable.

Additional gear

Other possible gear improvements include the addition of a HAAS, section 5.2.1, if a tree frog system is not adopted.

Finally, it is recommended that a yella grapnel (section 5.2.1), or a similar device, be added to the climbing gear list if problems reaching the tree trunk upon ascent of the climbing line persist.

Ascent Recommendations

In the event that the installation of the RFCx's AMD does require the installer to scale the tree, and the recommendations made above still leave much to be desired in areas of time and effort required to climb the line, the ascent process can be mechanized. A benefit of such an approach would be the use of existing climbing gear as a back up system in case of technical difficulties in the field.

Riggers Winch

The primary recommendation for the implementation of powered ascent would be the adoption of the riggers winch system described by Sean Cogan of Harken, outlined in section 5.2.1. This would provide the cheapest option among the power ascenders and the lowest weight.

WRAPTOR

If simple ascent is desired, the Wraptor by RopeTek described in section 5.2.1 is recommended based on its low cost and being specifically built for the arborist industry. While not as refined as the other power ascenders examined, its relative low cost compared to other available models make it the best ascender for experimentation in the field.

The ground winch setup described by the riggers winch system would also be available with the Wraptor acting as a ground winch.

Line Setting Improvements

Immediate improvements to the accuracy of setting lines can be achieved through the implementation of the Big Shot modification or the adoption of a pneumatic launcher.

BIG SHOT MODIFICATION

The Big Shot modification described in section 5.2.1 provides a fast and cheap upgrade to the equipment already possessed by RFCx. While it may not change the customer's general negative opinion of the Big Shot, it should provide a stopgap measure that can be implemented with minimal resources in an afternoon.

PNEUMATIC ANTENNA LAUNCHER

Of the line launchers examined in section 5.2.1, the DIY tennis ball antenna launcher designed by Alan Biocca Engineering is the recommended option. Lighter, cheaper, and more compact than the commercial pneumatic launchers, it can be constructed in an weekend for a minimal investment. The DIY nature of the launcher also aligns with the hacker nature of the RFCx's AMD.

6.2 Promising Technologies from SOA

The exploration of the current state of the art provided a number of interesting paths in the pursuit of an ideal solution for the installation of RFCx's AMDs. At this stage of the project these technologies represent a solution path for the task of elevating the device off the ground and will require further development to solve the full task of device installation.

6.2.1 Long Poles

As one of the first concepts suggested at the start of the project, the use of a long pole continues to provide interest as a solution. The use of pneumatic poles for military operations demonstrates their functionality under difficult operating conditions, as well as their stability at heights similar to the current installation target of 60 to 70 feet (18 to 21 meters) as shown in section 5.2.4.

6.2.2 Drones

The use of drones lends itself to a number of applications with respect to the needs of RFCx. As outlined in section 5.2.6, multi-rotor copters offer a range of solutions from line setting to full installs. Of particular note is their use in tying of knots for the construction of aerial structures, as this provides an interesting option for attachment to the tree.

7 Reflection and Next Steps: Transition to Concept Generation

Promising technologies from the search for solutions covered in section 5 where communicated with RFCx through the use of an shared Google document. This allowed the customer to stay abreast of interesting developments and to provide input throughout the project.

The recommendations outlined in section 6 were further discussed with RFCx during a series of long interviews that were conducted near the end of the first phase of the project. The customer's reaction to the results of the early recommendations triggered the transition form the product discovery stage of the project to the second phase of the project, concept generation.

7.1 Customer Reaction to Presented Results

The reactions conveyed by RFCx to the results of the search for solutions ranged from excitement to apathy. These reactions guides the path forward, by highlighting which solution paths to pursue in more detail and those to essentially drop.

7.1.1 Results of Immediate Improvements

CLIMBING METHOD RECOMMENDATIONS

Of the recommendations made for immediate improvement to the tree climbing methods based on industry practices, it was the false crotch that garnered the most attention, as it would eliminate the need for branch isolation - one of their current pain points.

ASCENT RECOMMENDATIONS

The riggers winch system described in 5.2.1 received positive feedback. Specifically stating that, "If our partners are going to be tree climbers they should be doing something like that. That would be a great recommendation (Grenell, 2015)."

LINE SETTING IMPROVEMENTS

The Big Shot modification was meet with little fanfare. It is likely that this stems from the fact that the Big Shot, and line placement in general, was described as a major pain point.

The recommendation of the pneumatic antenna launcher received a more positive reception. Up to this point RFCx had not looked at alternatives for line launchers.

7.1.2 Concept Preference

LONG POLE

One possible solution received a far greater positive response than any of the other technologies covered by the search for solutions - the use of an extendable pole. First suggested as the military grade 15 meter pneumatic pole by Vertmax in section 5.2.4, the idea quickly grew into the desire for an extendable pole that could be employed to quickly install a host of devices temporarily for diagnostic testing before a permanent installation was completed.

The initial excitement would persist until the following interview three weeks later. As such, it heavily influenced the next phase of the project. This will be discussed in further detail in section 9.2.

7.1.3 Varied Response

DRONES

The use of drones evoked a mixed response. On one hand, their popularity in the media makes them a natural initial inclination when searching for a new technology to utilize. The capabilities by the quad-copter deployed by ETH Zurich for aerial construction were viewed not only as an applicable solution, but also a tool that would excite third parties.

There was also some interest in utilizing a multi-rotor copter for potential line setting and cell service testing.

In the end, drones were viewed as an unreliable solution moving forward due to their tendency to crash; especially with the wide range of partners and associated operator skill that would be encountered in the field. Coupled with the stated principle of "...less automate, more obvious ...," (Topher White, 2016), the complexity of drones make them an unlikely solution for the scope of the current project.

7.1.4 Concept Elimination

TREE CLIMBING

It became clear during the interviews with RFCx that tree climbing was not viewed by the company or their perspective partners as a scalable solution; a central goal of the company. Clarification of the techniques employed and areas where time improvements could be made further indicated that major improvements would not be made in the physical climbing of the trees. Therefore, for the purposes of this project, tree climbing would be removed as a viable solution.

7.2 Transition to Concept Generation

An increased understanding of the operating environment and employed techniques obtained from the background research into the current state of the art lead to a more comprehensive understanding of the customer's problem and their need for a novel solution for the installation of their AMD.

A key clarification was that the main time concern with tree climbing was not in the actual climbing of the line, but found to be in the inaccuracy line setting; specifically with the Big Shot. The procedure can take from as little as 10 minutes to as long as 40 minutes. Furthermore, a total installation time of a device via climbing the tree of 1.5 to 2 hours was not deemed unreasonable when discussed with professional arborist Dan Holliday (2015). This is far different from the initial perception that the actual rope climbing was comprising the major component of the time required to install the AMD once a tree had been selected for installation. As it stands, the physical climbing of the rope, once set, has been conveyed to be in the five minute range. While the application of existing climbing systems, such as the tree frog system, can reduce the physical effort required, it would not have a significant impact on the overall installation time.

Another of the initially stated pain points, the need to re-climb trees due to being too far away from the tree trunk upon ascent of the climbing line, had been solved by the customer through the use of a lanyard.

Another key clarification was the need for a solution that is not only technically scaleable, but also sellable to partners and investors as scaleable. At this time it was the view of RFCx that they did not possess a scaleable solution. It was expressed that due to safety concerns, many of their partners would not allow their employees to climb trees, further adding to problem of scalability.

This increased comprehension of the needs of the customer, and the progress made in the research into the current state of the technology available, made it clear that the project would need to transition to the development of novel solutions to properly address the needs of customer. Therefore the project would transition from the product discovery phase into the concept generation phase.

7.3 Reflection

At this stage it is possible to reflect on the recommendations with respect to the original mission statement, customer needs, and customer pain points. When viewed through the lens of the mission statement, RFCx's current method meets these needs - as proven by the fact that they have been training their partners on the ground to climb trees for the purpose of device retrieval and installation - though be sure it is not the preferred method. One avenue of meeting the key goal of installation time reduction is through incremental improvements to the current method, versus the creation of a novel technique.

A review of the customer pain points - which are reflected throughout the mission statement and customer needs - show the adoption of the tree frog system or the rigger winch system would address the issue of physical effort and the original issue of time spent climbing the tree. Clarification of the tree climbing process revealed that the physical act of climbing the tree was not the time issue. The need to repeat the climb setup and ascent due to the climber not being horizontally close enough to the tree trunk to perform an installation was solved by RFCx through the use of a lanyard. The problem of the starting branch potentially being 200 feet away is addressed by the pneumatic antenna launcher. Safety of the rope climbing was addressed by Killagore (2008) in his review of the Doubled Rope Technique (DdRT) technique, where over 500 climbs over 8 year produced not a single incident.

A main take away from the discussions was that while climbing trees for device installation is a solution for the pilot stage, it is not seen as meeting the clarified requirements of being scalable and sellable, as third party partners are simply not going to want to climb trees.

Part II

Phase 2 - Concept Generation

8 Info: Long Form Interview

Two interviews were conducted near the end of the state of the art research phase of the product development process. They allowed for the exchange of information in the form of allowing RFCx to provide a detailed overview of their operations in the field, while providing a forum for the review of the results of the SOA research. This would provide an update to the background information presented in section 2.

The interactions provided an updated understanding of the customer needs and provided guidance for the next steps of the project; both in terms of the scope of the project moving forward and in the early preference and dismissal of solution concepts formulated in Phase 1 of the project, as discussed in section 7.1.

Both interviews were conducted over online video messaging (Skype), with an audio file recorded for each. Highlights and transcripts form the interviews are available in appendix 3.

8.1 Operations in the Field

Dave Grenell of RFCx provided a step by step recount of the field operations required in setting up their system during a pilot project in Cameroon. An overview of the relevant steps will be provided below, while the transcript from the interview is available in appendix 3.2.

Field operations were conducted in four phases. Phase one is reconnaissance to check for cellular service, where promising locations identified on a map supplied by local partners is verified. This process can take weeks. Phase two is reconnaissance for the identification of suitable trees for installation within the areas of forest identified in phase one. In the third phase multiple devices are installed at low elevations for diagnostics and in phase four the permanent installation of AMDs are conducted at locations selected based on the analysis of the diagnostic data collected from phase three.

In phase three, more devices than necessary to monitor an area of forest are installed to determine the best location for a permanent placement. Information on cellular signal, sunlight, and acoustics are gathered back at the base camp - over the course of a couple of days - and evaluated to determine the best locations for a permanent installation.

As these are temporary installations, in an ideal situation they would be installed without the installer climbing the tree. In Africa, it was discovered that signal tests performed at low elevations were not highly representative of the signal received at higher elevations. As described by Topher White, it is “a totally different place in terms of reception.”

Once the data has been analysed, phase four can begin. The operators head back into the forest with full set of climbing gear to perform the permanent installations, with the goal of three installations per day. Permanent installations are conducted by manually climbing the tree. Devices are installed as high as necessary to obtain a connection with the cellular network, with the assumption that canopy branches will not begin before 100 feet (30 meters) from the ground. Upon reaching the installation height the installer will throw a lanyard around the tree trunk to secure themselves close to the tree trunk, prior to the attachment of the AMD to the tree trunk with screws. Back at base camp further diagnostic data would be collected and monitored.

A number of steps are required in preparing a tree for climbing. First, a safety walk around the tree is performed to check for hazards. This would have also been conducted in phase two when identifying potential trees for installation and before any climb in general, including if climbs were performed in phase three. Next, a patch of ground is cleared with a machete to provide an operation area where a tarpaulin is set down before setting up the Big Shot - as described in section 5.2.1. The Big Shot is employed to set the throwline, which is used pull up the climbing rope. The setting of the throwline is reported to take anywhere from ten minutes to an hour, depending on the conditions and ones luck. At this point the tree is ready to be climbed. The operator dons their climbing safety gear, clips into the system, and ascends the rope.

8.2 Updated Climbing Method - Video

New videos were made available by Rainforest Connection that revealed in clear detail the climbing method being currently utilized and taught to partners in the field; a Rope Wrench based SRT system, with a foot ascender and HAAS. This cleared the confusion surrounding the method being employed by RFCx in the field, as it was unclear from conversation and video if a DdRT system or an older SRT system was being utilized.

8.3 Updated Device Specs - Topher

An update on the AMD and its installation components were also provided at this time. Designs of the mount and the box for encasing the up-recycled mobile phone were reviewed and shared. The mobile phone casing had increased in size since the start of the project.

The AMD had begun to be employed in a modular method. When required, additional solar arrays and a directional antenna were added to the installed system as required. The additional array is similar to that attached to the base AMD, except that it does not require the weather proof box that encases the up-recycled mobile phone. It is attached with the same mount. The directional antenna is typically installed on the tree four to five feet from the base AMD. Both yagi and parabolic antenna are employed. It was noted that the installation of these modular elements did not need to be added to the current scope of the project.

8.4 Customer Statements - Pain Points

Over the course of the interviews a number of additional customer pain points were noted that would expand the interpreted customer needs. While not representative of all of the customer needs that would be determined from the communication with the customer, they do represent some of the loudest complaints. These pain points consisted of; the setting of throw lines, particularly with the Big Shot; the quality of installations performed by partners in the field; the lack of a sellable solution to present to investors when inquired about the scaling of the project; and the danger and liability associated with climbing trees.

8.5 Refined Project Scope

At this time of transition from the product discovery phase to the concept generation phase, it was encouraged by the customer that the scope of the project be limited to the improvement of only one or two aspects of the project. Based on the changing nature of the required adjustment of equipment in the tree by the installer - such as the addition of the modular components - and the belief that placement of the the AMD would be simplified over time through improvements to the technology, it was determined that placement of the device would not be one of the solved problems. Placement in this case refers to the adjustment of the AMD in the tree. The project would still seek a solution to the attachment of the AMD in the tree. It is the clear expression of RFCx that the project would be deemed a success if it is able to provide a single additional tool that can aid in an aspect of field operations.

9 Goal: Updated Mission Statement

The expansion of information provided from the in-depth interviews conducted with RFCx resulted in the refinement of the projects goals and the identification of an additional value added outcome for the product development project. This necessitated a new iteration of the mission statement presented in phase 1, section 3.1, to accurately guide the future stages of the product development project.

9.1 Phase 2 Mission Statement

The refinement in understanding of RFCx's mission goals are articulated in the updated mission statement presented in table 9.1. To highlight the modifications made in the new revision additions to the mission statement are presented in emphasized text, while subtractions are indicated by stroked-through text. These formatting additions would not be present in the physical document utilized to guide the next steps in the product development process, but are included in this report for clarity.

The following sections highlight the updates made to the mission statement. Unless otherwise noted, the information provided with the original mission statement in section3.1 remains valid and will not be repeated in this section.

9.1.1 Product Description

The product description was updated to include the key requirements of a scalable and sellable installation technique. The two requirements are connected, as in order for a technique to receive the investment required for the project to scale, it will need to be viewed by investors and partners as a scalable technique. It is not sufficient for the developed concept to merely address the physical problem of installing an audio monitoring device in the tree, but must also address the outside perception of the technique.

9.1.2 Benefit Proposition

The benefit proposition was updated to include the desire for a ”simple to communicate idea”. An idea that is simple to communicate - regardless of the complexity of its implementation - aids RFCx in generating and securing additional support for the company, in the form of additional partners and investors.

9.1.3 Key Business Goals

An updated list of the key goals that support the company's overall strategy.

Rapid expansion - scalable: A core goal of RFCx is the rapid expansion of their system to combat illegal logging as quickly as possible. Any installation technique must be developed with the physical demands of rapid scalability in mind.

Sellable (exciting) idea: The simplicity of the core concept of RFCx - the placement of an up-recycled cell phone to listen for chainsaws - has been identified by RFCx as a key strength in their ability to attract partners and investors. A simple idea that has the ability to excite investors and members of the secondary market aids the company in securing additional funding and partners in the field.

9.1.4 Target Markets

There have been no changes to the project's target markets.

9.1.5 Assumptions and Constraints

An updated expansion on the the assumptions and constraints contained within the mission statement. These statements are attached to the mission statement outlined in table 3.1.

Low physical effort: In the original mission statement it was assumed that in order for a technique to be adopted by RFCx, it would have to not increase the physical effort already experienced in the current tree climbing method. The update relates to the assumption by RFCx that for the installation method to be readily adopted by their partners in the field that it will have to entail less physical effort than the current method.

Teachable and retainable: In addition to the installation solution being teachable and repeatable by members of the secondary market, the retention time of any such training must also be taken into consideration. A lack of retention between employment of the installation technique - with a time lapse of half a year expected - can increase the risk of injury and decrease the quality of the installation.

Device requires adjustment during installation: As part of the updated scope and boundary of the product development project, it has been determined that device adjustment will be excluded from the scope of the developed concept for an installation technique. This is due to belief that while it is a key component of the current installation process, its importance will diminish in the future with technical improvements to the monitoring device.

Climbing trees not sellable as scalable: Based on the experiences of RFCx, climbing trees is not regarded as a scalable solution by interested third parties. As stated by Dave Grenell, "people interested in supporting RFCx, but only if you can scale it." Issues include that partner organizations will not allow their employees to climb trees due to safety concerns and that tree climbing has made RFCx's field partners nervous in the past.

Simple - "Less automate, more obvious . . . " (White, 2016) A guiding principle for the project put forth by RFCx, that developed concepts should avoid complicated systems.

Testable : Based on the company belief that a concept piece is never quite useful until you test it, developed concepts should lend themselves to quick field testing, without the need for huge investments.

9.2 Additional Goal - Temporary Device Installation

Through the discussions with the customer on the results of the state of the art search for solutions, and the expanded detail provided on the operational steps conducted in the field, it was discovered that the temporary installation of AMDs for the diagnostics stage of the system set up would provide added value to the company. This would be seen as providing RFCx with, “one more tool.” (Grenell, 2015).

During previous pilot projects, it had been discovered by RFCx that the reception data received from devices installed close to ground level for the diagnostics stage of the field system set up were not reliable indicators of the reception experienced by full height installations. As previously noted, it was deemed, “a totally different place in terms of reception.“ Therefore, a solution that would allow for the testing of cell service - either over the course of a few hours or a night - without the need for the physical climbing of the tree, would be considered a real asset to the company.

The pursuit of such a solution would follow the guidance provided by the mission statement in table 9.1, with little modifications required. The meaning of the term installation in the product description would need to be defined and expanded. In phase 1, installation was assumed to refer to a permanent, full height installation - as defined by the target specification of an installation height of 60 to 70 feet (see metric no. 2, table 4.2). To accommodate this new solution path, the definition of installation would be expanded to include temporary installation at potentially lower elevations. Such a solution would place additional importance on the need for device retrieval - a need outlined in phase 1 in table 4 (need no. 9).

Table 9.1: Phase 2 - Mission Statement

Mission Statement: Rainforest Tree Installation Method	
Product Description	• Safe, adaptable, *scaleable and sellable* technique for the installation of RFCx audio monitoring devices in a wide range of remote rainforest environments.
Benefit Proposition	• Quick and easy installation of device • Requires a low level of training and expertise • Facilitates expansion of monitored rainforest • *Simple to communicate idea*
Key Business Goals	• Adaptable to variety of tree characteristics • Reduce time from current method • Safe method • Adoptable by partners in the field • Shipped as an off the shelf product • Low cost • *Rapid expansion - scalable* • *Sellable (exciting) idea*
Primary Market	• RFCx employees
Secondary Markets	• Indigenous people of the rainforest • Government employees • Park rangers • NGOs
Assumptions and Constraints	• Environmentally friendly • Low impact on trees and environment • *Low* physical effort • Teachable *and retainable* • Durable • Compact - Manually carried • ~~Device requires adjustment during installation~~ • *Climbing trees not sellable as a scaleable* • *Simple - "Less automate, more obvious"* • Testable

10 Guide: “Clarify the Problem”

The first step in the concept generation method proposed by Ulrich (2003) is to “Clarify the problem,” - to act as a guide for the ensuing external and internal search for solutions. To clarify the problem a general understanding of the problem is developed and combined with the deconstruction of the problem into sub-problems. The general understanding of the problem is constructed and reflected in the mission statement, customer needs lists, and the early specifications; the inputs to the concepts generation process.

To support the general understanding of the problem, the customer needs list first presented in section 4.1 is updated with customer statements garnered from the long interviews outlined in section 8; followed by the decomposition of the problem in support of the concept generation phase.

10.1 Updated Customer Needs

The open discussions conducted with RFCx through the long interviews presented in section 8 provided additional insight into the customer’s needs. New needs were identified, while the definition of some of the previous needs established in section 4.1 were expanded upon and emphasized. Emphasized and updated needs have been included in table 10.1 with the same need number as in table 4 and their new associated customer statements. The customer statements are presented verbatim to preserve the intention behind the interpreted need. New needs continue the numbering from table 4. The omitted need of device placement has been stroked through to show its removal. Multiple customer statements often relate to the same need. In such cases only a single customer statement is presented in table 10.1. Latent, or hidden needs - needs which the customer is unaware of - are highlighted with a (!) designation.

The highlighting of the updated customer needs should not be taken to signify a decrease in the importance or validity of the customer needs presented in phase one, as table 10.1 is an expansion of the original needs list. The entire list of customer needs is to be utilized in the guidance of the concept generation process.

Table 10.1: Updated Customer Statements and Interpreted Needs

No.	Question/Prompt	Customer Statement	Interpreted Need
3	What don’t you like about the current solution - tree climbing	It’s highly, highly, highly labor intensive.	Solution is low physical effort
4	On scalability and sell-ability to partners/investors.	…because like we said it, 20 countries have invited us. They don’t always have funding …	Solution is low cost
5	Need for visual aid for remote installations.	I think it’s got to be really simple.	Solution is simple to operate

Table 10.1: Updated Customer Statements and Interpreted Needs

No.	Question/Prompt	Customer Statement	Interpreted Need
7	Speaking on simplifying one aspect of the project	That's huge. That saves us like 3 hours.	Solution saves time
14	In tree adjustment	Right now you need the human element for adjusting the devices in the tree.	~~Solution allows for device adjustment in the tree~~
16	What don't you like about the current solution - tree climbing	The dangers and the liabilities	Solution is safe
19	On scalability and sell-ability to partners/investors.	Because people ask, "Oh how would you do this if you want to protect in 15 countries?" There's currently not a great answer	Solution is sellable
20	What don't you like about the current solution - tree climbing	I can tell you one thing, all these folks go giggles over new technology	(!) Solution has "wow" factor
21	Explore the greatest pain points	Being able to do, maybe just a cell service test, . . . [1]	Solution allows temporary testing (cell service, sunlight) at elevation
22	Setting the line is a problem by the sounds of it	If you talk to people who are like, "we're interested in supporting your solution, but only if you can scale it,"	Solution is scalable
23	On scalability and sell-ability to partners/investors.	The simpler the better, if it's imaginable. It really does help our communication.	Solution is simple to communicate
24	Mention mods to Big Shoot.	Climbing trees requires a lot of gear. . . and lightening that load . . .	Solution is light weight

10.1.1 Emphasized and Expanded Needs

The emphasised and expanded needs range from need number 3 to 19 in table 10.1, and will be expanded upon below.

[1] Full customer statement, "Being able to do, maybe just a cell service test, over the course of an hour or two, or over a night; without necessarily considering a permanent installation; without having to climb the tree, could be a real asset."

LOW EFFORT (NO. 3)

The customer need for low physical effort has been expanded upon from a general complaint of the current system, to being stated as one of the major pain points, and as a barrier to system adoption by their partners in the field. For conciseness, only one of the customer statements has been included in the presented table.

LOW COST (NO. 4)

While low cost was always an inherent need of the customer, a solid example of cost forming one of the barriers to further project expansion and adoption was provided in the update customer statement; emphasising the importance of a low cost solution.

SIMPLE TO OPERATE (NO. 5)

The need for a simple solution has been emphasise and expanded upon by new statements made by the customer. It has grown in importance from an expressed wish to a core conviction, while expanding to encompass the new need of a simple to communicate solution.

TIME SAVINGS (NO. 7)

A significant time reduction in any aspect of the field operations remains a strong customer desire.

SAFETY (NO. 16)

The need for safety has expanded to encompass not only the reduction of the potential of an incident occurring, but also the severity of an incident if it were to occur; highlighted by the customer statement made by Grenell of RFCx - "Imagine if people got hurt, it would probably kill the program."

The need for a safe solution also concerns the retention time of the training provided by RFCx to their partners in the field. With a probable down time of half a year between the utilization of a taught technique, the omission of steps in the solutions set up and operation can increase the risk of injury.

10.1.2 Omitted Needs

ADJUSTMENT IN TREE (NO. 14)

As noted in the revised mission statement presented in section 9.1, the adjustment of the device in the tree, prior to attachment, has been removed from the scope of the project.

10.1.3 New Needs

The new communications with the customer brought to the fore six new interpreted needs; the majority of which related to their need for a sellable idea to present to potential investors in the project. Both the inherent need for a sellable concept, and what was required of a concept to be considered sellable. The new needs are reviewed below.

SELLABLE TO 3RD PARTIES (NO. 19)

The need for a believable concept that can be used to attract investors was flagged as a key customer need throughout the second round of communications with the customer highlighted in section 8. The need for a sellable concept encompasses other customer needs, as a sellable concept is required to be viewed by interested third parties as not only as safe, but also scalable.

The perception of the safety of the operations performed in the field effect the sellability of the RFCx system as a whole. As stated by Grenell, an obstacle to attracting third parties is that there are, "always people in these organizations looking for reasons not to do something (2015)"

EXCITING TO PARTNERS (NO. 20)

A latent need identified in the second iteration of the customer needs was the benefit provided by the solution possessing a wow factor; to inspire the adoption of a solution through the excitement it generated in the user. An example was given of partners in the field finding hex-copters to be like a video game.

TEMPORARY TESTING (NO. 21)

As highlighted in section 9.2, the need for the temporary placement of a device for diagnostic testing prior to permanent installations was identified as a method of providing a high value concept to the company.

SCALABLE (NO. 22)

The scalability of the developed concept is not only important for the physical expansion of RFCx's network of protected rainforests, but also for generating support for the company as a whole. This is connected to the customer need for a sellable solution.

SIMPLE TO COMMUNICATE (NO. 23)

An expansion of the initial need for a simple solution includes the need for the generated concept to be simple to communicate, as part of the need for a solution that garners support from third parties. RFCx attribute the simplicity of the idea behind the company - of solar panel powered cell phones - to part of their current success.

LIGHT WEIGHT (NO. 24)

The need for a light weight solution was previously reflected in mission statement through the stated assumption that any developed solution would need to be manually carried through the rainforest and through the weight requirement specified in table 4.2. During the latest round of communications, the customer expressed a more direct wish for lightening the load carried the field.

10.2 Problem Decomposition

Problem decomposition is the slicing of a large, complex problem into a number of simpler subproblems. Many different schemes have been developed for the breaking down of problems. The scheme selected at this stage of the project was "decomposition by sequence of user actions." When the problem is decomposed into its functional elements, they are stated in a generalized manner to avoid the implication of specific solution principles. (Ulrich, 2003, pg. 123).

The problem to be decomposed is the installation of an RFCx AMD, both permanent and temporary. To facilitate the break down into a sequence of actions , the current installation steps performed by RFCx in the field are used as a guide.

For this stage of the project the identification of the signal, material, and energy flows between the subfuctions would only serve to limit the concepts to be developed by making premature assumptions on the nature of the solution. Therefore on the advice of Ulrich (2003) the subfunctions are presented as a simple list, without identified connections. To foster the generation of novel concepts it is beneficial to remove the order of operations from the subfuctions. The subfunctions are presented in this manner in figure 10.1 and described below.

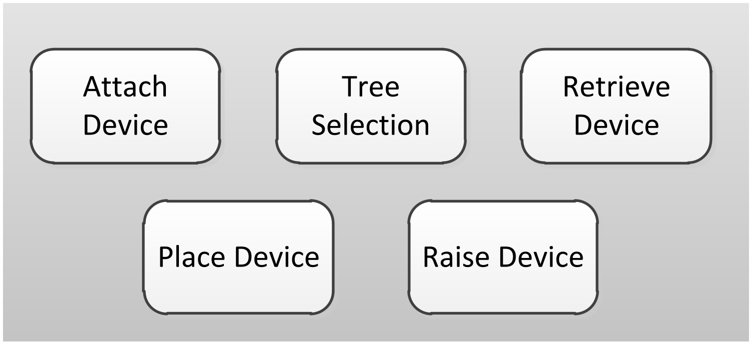


Figure 10.1: Phase 2 - Problem decomposition

Tree Selection: The identification of a tree suitable for installation. This includes the initial identification of a tree as physically suitable for the installation of an AMD - in terms of sunlight, cellular service, acoustics, and safety - and the final selection of a tree for permanent installation post diagnostic analysis.

Raise Device: The elevation of the AMD to the installation point on the tree.

Place Device: The adjustment of the AMD at the installation point to optimize cellular signal and sunlight.

Attach Device: The attachment of the AMD to the tree.

Retrieve Device: Removal of the AMD from the tree and its return to the ground.

Focus on Critical Sub-Problems

The decomposition of the problem allows for the identification of critical subproblems, to focus the efforts of the project. Critical subproblems are those determined to be the most critical to the success of the end product. The solution of these problems form the focus of the search for solutions, while the solution of non-critical subproblems are deferred. (Ulrich, 2003, pg. 123)

In the case of RFCx's AMD, the critical subproblems were selected to be “Raise” and “Attach” device. Without meeting these two subproblems it would be difficult for a concept to be a successful solution, although not impossible. The solution of these problems would be the focus of the search for solutions.

“Retrieve” device was designated as a less critical subproblem. Its solution should be kept in mind when developing concepts, but it is not deemed necessary for a successful solution.

The remaining subproblems are designated as non-critical subprobelms. “Place” device had already been removed as a subproblem as noted in the customer needs, section 10.1. For the subproblem of “Tree selection”, its solution will be dependent on the solutions to the critical subproblems that will determine the installation method.

11 Search for Solutions: External and Internal Search

Focused on the two critical subproblems identified in section 10.2, the search for solutions consists of simultaneous external and internal searches to facilitate the development of solution concepts. The external search provides inspiration for the development of concepts in the internal search, which in turn further directs the external search.

The search for solutions of subproblems typically generates solution fragment - subsolutions - whose combination form the a full solution concept. As these solution fragments are generated, they are collected and organized in concept classification trees; a powerful communication tool in concept generation that facilitates the division of solution fragments into independent categories. (Ulrich, 2003, pg. 132). Exerts from the concept classification trees will be provided throughout the section to display the solution paths explored throughout the external and internal search, with the full concept classification trees available in appendix 2. The concept classification tree is further explored in section 12.1.

The section will be structured to show the external and internal search for each subproblem one after the other, while it is to be understood that the two searches were taking place concurrently.

11.1 External Search

The external search for concept generation is a continuation of the SOA conducted in Phase 1, presented in section 5.2.

The external search for solutions began with the direct continuation of the state of the art search conducted in phase one for the expanded goal of temporary installations. The search would continue to be focused on comparable industries for solutions.

After expanding upon the state of the art search, the external search would be oriented around the solution to the defined critical subproblems, in contrast to being focused on comparable industries.

11.1.1 SOA Expansion

During the long interviews that provided the new information guiding Phase 2, it was determined that a solution that would allow for an improved method of conducting low elevation installations would be valuable to the company. Therefore the SOA was extended in search of a method to place a device at a low height that the operator could reach with minimal effort.

Tree Hunting

The sport of hunting from a tree and its associated gear was identified as a promising comparable industry that had yet to be fully explored in the state of the art research. With the height requirement for placement of the AMD being loosened with the addition of the goal for temporary installations, climbing techniques employed by tree hunters became viable solutions.

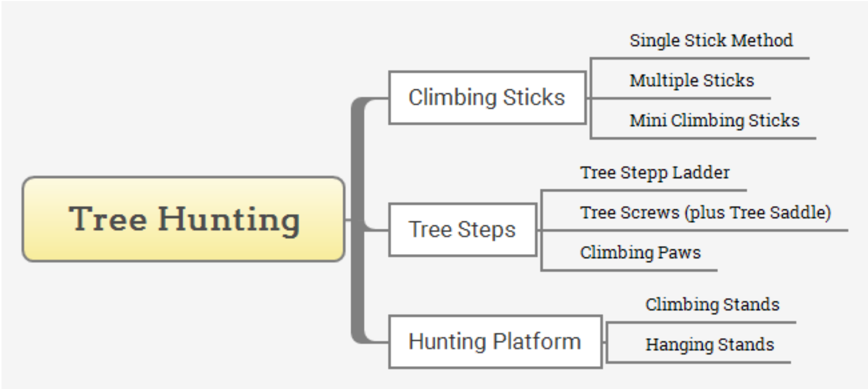


Figure 11.1: Concept classification tree - tree hunting

Stepp Ladder

An improvement on the basic tree step described in section 5.2.1, the Stepp Ladder allows for the quick installation of temporary foot support onto the trunk of the tree. It consists of a metal v-shape step that is tied around the tree trunk and pulled vertically downward to lock the step in place. Each step can be installed in approximately 20 seconds. A set of 12 steps allows the user to climb 24 feet, with each step weighing slightly under a pound (450 grams).

The Stepp Ladder - or any other tree step - must be used with a linesmen belt or life line tied around the tree trunk to safeguard the climber from falls.

Climbing Sticks

Climbing sticks provide an alternative approach to the traditional tree step. Constructed of a light weight pole with 3 to 4 steps, the climbing stick is secured directly to the tree trunk through the use of webbing or rope - depending on the manufacturer. They are intended to be used with a fall arrest system, linesmen belt, and optionally a tree tether.

Standard climbing sticks are designed to attach to tree trunks with a diameter of 4 to 22 inches (10 to 56 cm), with extensions available. Contact with the tree is made with a pivoting v-bracket, which allows the climbing stick to be placed on irregular tree trunks.

The intended use of the climbing sticks is to set additional sticks in succession until the desired height is reached. A standard set of 3 to 4 sticks allow the climber to reach a height of 16 to 23 feet in 5 to 7 minutes. A common weight rating for climbing sticks is 350 pounds.

Inventive users have developed a one stick climbing method, where the climber utilizes their life line to sit back in their harness while the climbing stick is removed and reattached higher onto the trunk of the tree. This allows the for the climber to potentially climb to any height with only a single climbing stick.

Tree Hunting Platforms

Tree hunting platforms are generally grouped into two categories; climbing tree standards and hanging tree stands. A climbing tree stand allow the operator to climb the tree with the hunting stand, while a hanging tree stand must first be set in the tree; typically from a ladder.

The climbing tree stand generally consists of two platforms with strapping that encircles the tree trunk. When weighted the platform is secured onto the tree trunk. One platform is for the operators feet, while the other is for their upper body. By alternating which platform bears the operators weight, the climber is able to advance the unloaded platform vertically along the tree trunk until the desired height is reached.

(a) Tree Stepp (Wild Edge Inc, 2016)

(b) Lone Wolf Climbing Stick (Lone Wolf Stands, 2016b)

(c) Lone Wolf Climbing Stand (Lone Wolf Stands, 2016a)

Figure 11.2: Tree Hunting Gear

11.1.2 Raise Device

Of the two identified critical subproblems of ”Raise” and ”Attach” device, ”Raise” device was selected as the first of the two problems to be explored. The results of the state of the art external search completed in phase one marked long poles as a solution path containing promise. Coupled with preference shown by the customer, research into long poles would receive the bulk of the focus of the external search .

Long Extension Poles

The investigation of long extension poles spanned across a broad number of industries, including window washing, antenna masts, and military operations; and yielded the identification of a number of distinguishing characteristics. Poles across all industries are characterized by their method of extension and material of construction.

The method of extension divided the poles as telescopic and segment poles. Telescopic refers to poles whose segments nest inside one another when the pole is retracted; a fishing rod is an example. A segment pole is extended by physically attaching pole lengths together end to end. The Add-A-Pole pole saw included in the initial external search in section 5.2.7 is an example of a sectional pole. An unique pole type was discovered in the external search in the Rolatube expanding masts.

Common materials for the construction of extension poles were aluminium, fibreglass, and carbon fibre; with all three commonly occurring within an industry. A rule of thumb proposed by Brodex (2015) when describing their water fed poles (for window washing) states that fibreglass are the cheapest budget poles, aluminium are for long lasting workhorse poles, and carbon fibre is great for heights as it is light and rigid, but expensive and brittle. Further research into available poles confirmed this assertion and directed the search towards carbon fibre poles for their rigidity and low density, while their use in military applications attested to their durability.

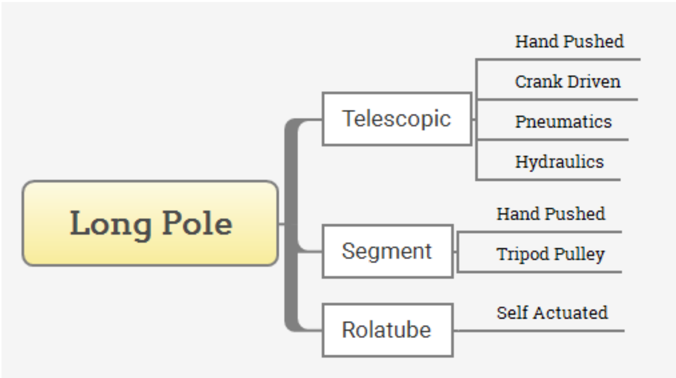


Figure 11.3: Concept classification tree - long pole

Telescopic Extension Pole

Telescopic poles are a popular product in the market of extension poles, due to their compact nature.

The majority of poles are hand operated, where the pole is extended, retracted, and locked in place by the operator by hand. Military applications expand upon the mechanism for expansion, with poles extended by hydraulics, hand cranks, and pneumatics. The Vertmax by ResQmax highlighted in section 5.2.4 is an example of a pneumatic powered extending pole.

Based on the customer need for a light weight and compact solution to transport through the operating environment of a remote rainforest and desire for a simple solution, hand operated poles were shown preference with respect to telescopic poles.

Hand Operated Telescopic Pole

The window washing industry is a producer of hand operated, carbon fibre telescopic poles; utilized in the production of water fed poles designed for the cleaning of building windows. Telescopic hand poles are available off the shelf with maximum extended lengths from 4.2 feet (1.27 meters) to 74 feet (22.26 meters)(Gardiner Pole Systems Ltd, 2014), providing the potential for temporary and permanent installations.

A supplier of water-fed poles and custom carbon fibre telescopic poles, Reach It, was contacted to determine the suitability of a pole for the installation of a AMD. The response indicated that they had tested a 50 foot (15 meter) pole with a 11 pound (5 kg) payload for the Israeli military that would serve the requested purpose (Tait, 2016).

Segment Extension Pole

Already noted for their use in the landscaping industry as pole saws, segment extension poles also find heavy use in the field of portable communication masts.

Carbon fibre military communication masts are designed to support 88 pound (40 kg) pay loads at heights up to 79 feet (24 meters), providing support far beyond the needs of a 3 pound (1.4 kg) AMD. The masts are supported on the ground by a simple baseplate or a tripod depending on the model and application, with guy wires dependant on the operating conditions.

The tripod base is of particular interest, as it provides a hand pulley and solid base for the raising of segments. In operation, a pole segment is locked into the tripod base with a pin. The second segment is connected to the bottom of the first pole, while the bottom of the segment is supported by a cup (resembling a pipe cap) connected to a pulley. The locking pin is removed and the pulley is hand pulled to raise both mast segments. The process is repeated until the mast is erected. This provides a structured and repeatable installation procedure.

While communication masts range in weights that would make them difficult to transport through the jungle, a man portable communication mast with a tripod base is available in a single backpack assembly; the ranger pack depicted in figure 11.4b. The ranger pack contains eight 4 foot (1.2 meter) carbon fibre pole segments to form a 24 foot mast that weighs a total of 65 lbs (30 kg), with a supported end payload of 50 lbs (22.7 kg). As this is far beyond the requirements of supporting a AMD, significant weight reductions are anticipated to be possible.

The set up time for the communication masts range from 20 to 30 minutes with two operators, for masts ranging from 49 to 78 feet (15 to 24 meters). This includes the time required to assemble the tripod base.

(a) Sectional mast with tripod base (Comrod Communication AS, 2016)

(b) Ranger pack (The Will-Burt Company, 2016)

Figure 11.4: Sectional communication masts

SELF ACTUATED POLE - ROLATUBE

RolaTube offered a unique approach to the extendable pole. Based on their proprietary “Bi Stable Reeled Composite Technology”, RolaTube offers a composite material that is stable in two forms. It is stable in its compact rolled up form, but once it is unrolled it springs out to its fully extended state - akin to a snap bracelet in reverse. Rolatube has adapted the technology to self extending communication masts, tripods, and poles.

To date rolatube offers masts in lengths of 2, 3, 4, 5, 7, and 8 meters. A 5 meter long rolatube weighs 11.55 lbs (5.25 kg) and can support a top load of 11 lbs (5 kg). While not as weight efficient as a telescopic carbon fibre pole, RolaTube self actuation has the potential to excite users through technology.

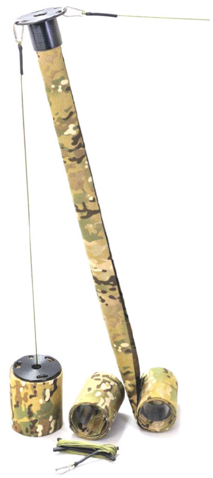


Figure 11.5: RolaTube mast (, REX)

11.1.3 Attach Device

The search for solution principles for the subproblem of ”Attach” device was dominated by two solution paths; solutions that attached the device through a loop of material, such as a rope; and solutions that utilized traditional mechanical fasteners, such as screws.

Solutions fragments that form the loop of material path were developed in the internal search, inspired by the tree attachment methods employed by the tree hunting gear explored in section 11.1.1. They are explored as part of the internal search for solutions in section 11.2.1.

The solution fragments for the mechanical fastener solution path are presented in figure 11.6. The solution path searched for general fastening methods, with an eye to those that could be adapted to be performed remotely. One branch that showed promise was that of explosive driver.

EXPLOSIVE DRIVERS

While the majority of methods listed are common household tools, the explosive driver branch was of note for its potential to be triggered remotely - particularly the ability to be triggered through physical contact. This could allow for a remote attachment without the need for an electrical signal.

The Hammershot by Ramset depicted in figure 11.7, employs a 0.22 calibre explosive to drive the fastener through wood and concrete. As its name implies it is activated through a hammer strike to the end of the tool.

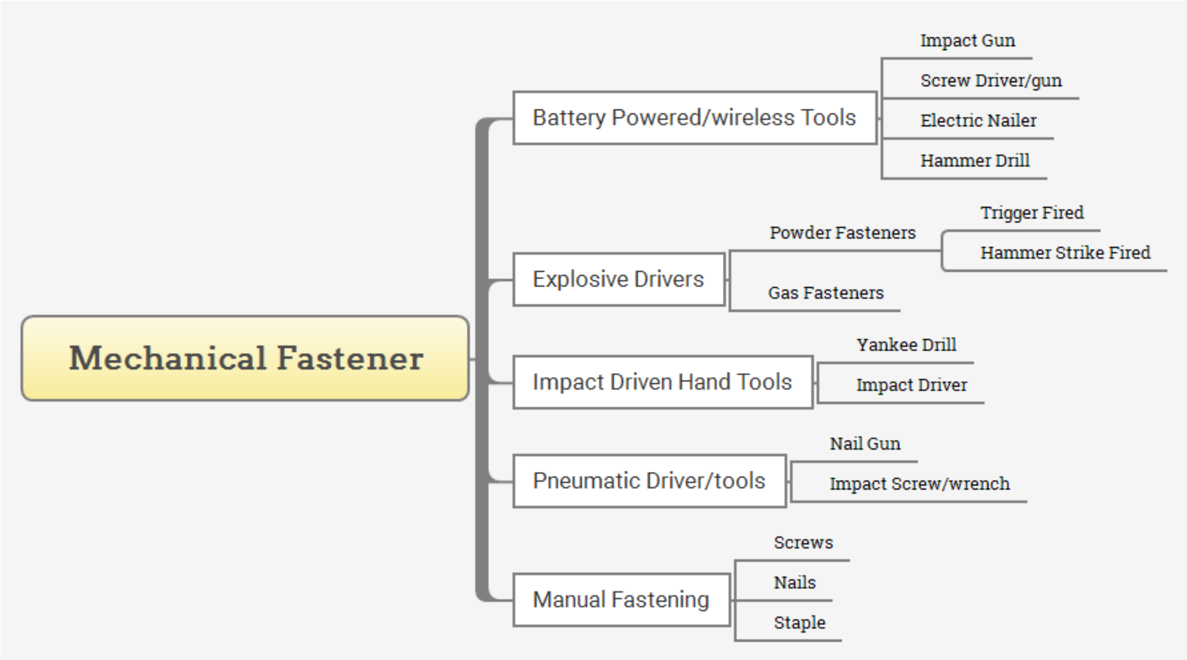


Figure 11.6: Concept classification tree - mechanical fasteners

Figure 11.7: Explosive driver - Ramset Hammershot (Ramset, 2016)

11.2 Internal Search

The internal search was fuelled by the inspiration generated through the external search for solutions to the critical problems identified in the problem decomposition; “raise device” and “attach device”.

Concepts were generated and explored through the utilization of hand sketches, with the goal of producing a large number of ideas. To facilitate the generation of a large number of solutions, judgement of the solution fragment was suspended until after the drawing was complete, and the quality of the sketches was not of high concern - the focus was on creation of the idea and the exploration of its boundaries.

In select cases were more information was deemed necessary and economical to produce, simple field tests were conducted.

The following section will highlight a few of the predominate concepts developed for the raise and attach critical subproblems. All generated concepts were recorded in a concept catalogue that is available in appendix 4.

11.2.1 Raise Device

The internal search for solutions to the subproblem of “raise” device focused on the adoption of the long pole solutions discovered in the external search. Sketches of the application of these technologies highlighted aspects of the concept that necessitated additional development.

For the application of long extension poles, additional subproblems were identified pertaining to the raising the device; the issue of the support required on each end of the pole, and how the pole would raise the AMD. Therefore the internal search shifted focus to the implementation problems of ground support and end support.

Ground Support

Methods of ground support drew inspiration from those solutions already employed with the long extension poles researched in the external search. Solutions ranged from the simple hand held, or no ground support, to mounting the pole on the side of a vehicle.

The tree mounted solution path was one left unexplored by the external search and thus the focus of internal concept generation.

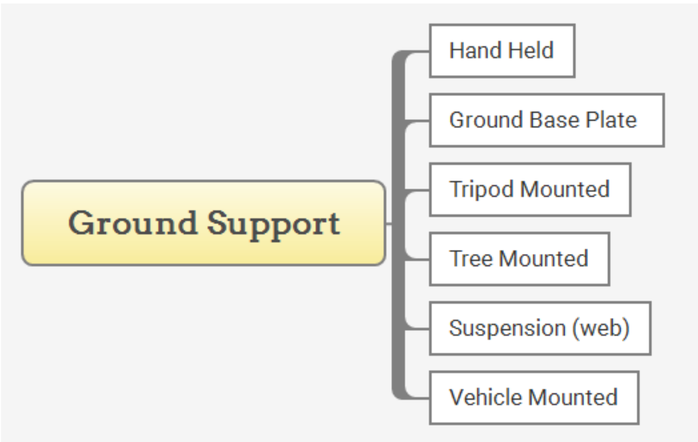


Figure 11.8: Concept classification tree - long pole ground support

TREE MOUNTED

The tree mounted solution path refers to concepts that utilize the trees present in the rainforest to provide a base of support. A concept known as the “rocker” draws inspiration from the solution principles found in the tree hunting climbing sticks shown in figure 11.2b, and the tripod supported sectional communication masts displayed in figure reffig:p2:mast. A concept sketch of the “rocker” concept is provided in figure 11.9.

The concept seeks to reduce the weight of a tripod supported mast by replacing the tripod with an end support attached directly to the trunk of the tree. The tree attachment function borrows the v-bracket and nylon webbing from the climbing stick. The pulley and the method of erecting the mast remain similar to that employed by the Comrod communication mast.

An additional feature of the rocker concept is the inspiration of its name. The mount is designed with a pivot point that allows for adjustment of the elevated pole end. This allows the end of the pole to be kept in contact with the trunk of the tree; either to support the end of the pole during erection of the pole or to place the AMD against the tree trunk prior to attachment.

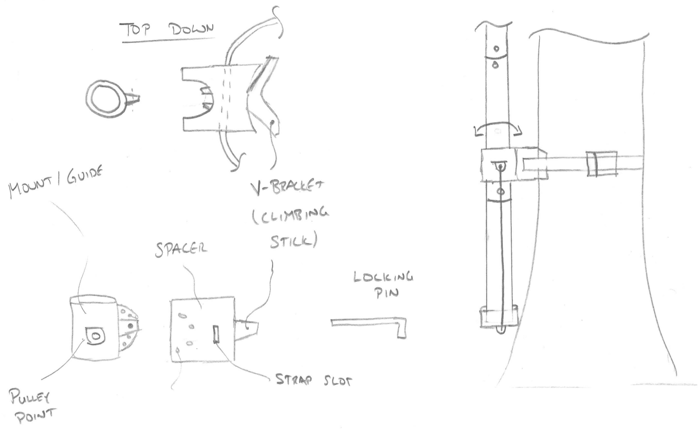


Figure 11.9: Concept Sketch for "Rocker" ground mount and pulley

End Support

The end support concept branch collected ideas for the support of the elevated end of the long pole. This could apply to providing support throughout the elevation of the pole or once the pole has been fully erected. This latter support could be required to secure the AMD to the trunk of the tree when a solution to the “attach” device problem is applied.

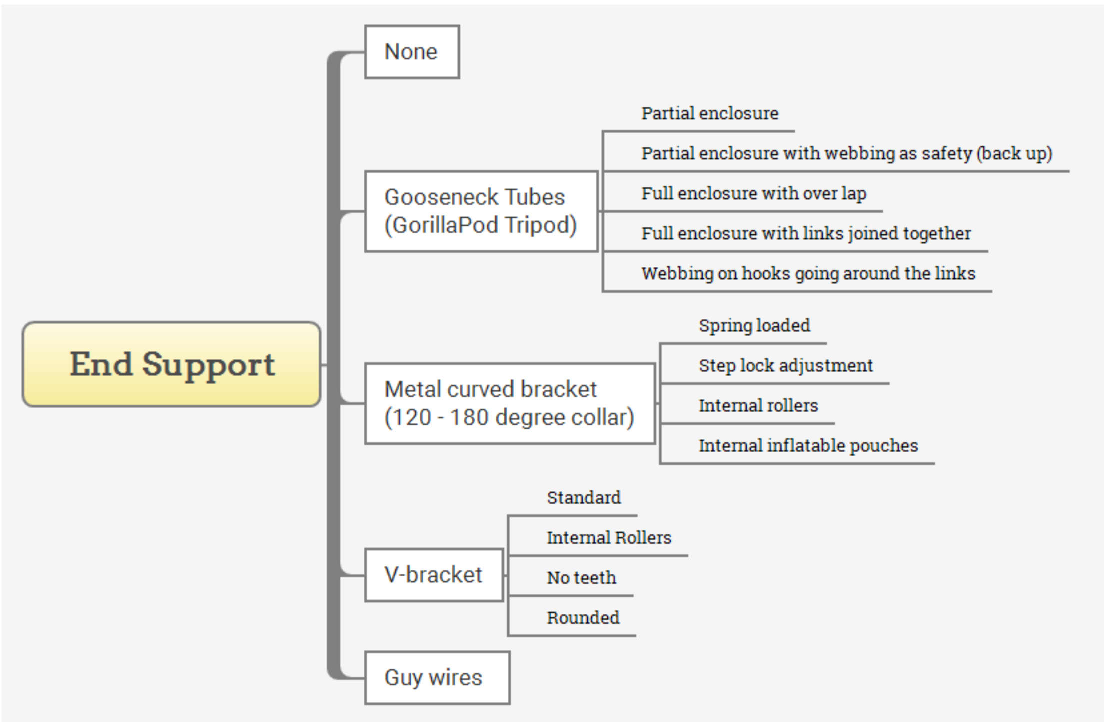


Figure 11.10: Concept classification tree - long pole end support

A favoured concept was the use of gooseneck tubes to provide flexible pole end support.

GOOSENECK TUBES

The gooseneck tubes solution refers to the use of flexible ball and socket joints commonly used in the camera tripods and made popular through the GorillaPod brand. The movement in the ball and socket joints allow for the adjustment to a range of tree shapes and arc lengths; while pods can be added or removed to adapt to the diameter of the tree trunk. Due to the ball and socket nature of the joints it is possible that in application the ball joints would spin, providing a low friction interface between the support and the tree trunk for the elevation of the pole.

Concept variations communicated in figure 11.10 explore different configurations of the tubes; such as a partial enclosure and the use of a backup tether, to prevent the end of the pole from pulling away from the tree trunk, as depicted in figure 11.11.

V-BRACKET

The V-bracket branch of the concept classification tree for end support encompasses methods of employing and modifying the v-bracket advertised by the climbing sticks highlighted in section 11.1.1. An example of the inclusion of a modified v-bracket in an end support concept is included with the gooseneck tubes in figure 11.11. The modification of the existing product is favoured for its design focused on the adaptability to irregular tree trunk surfaces.

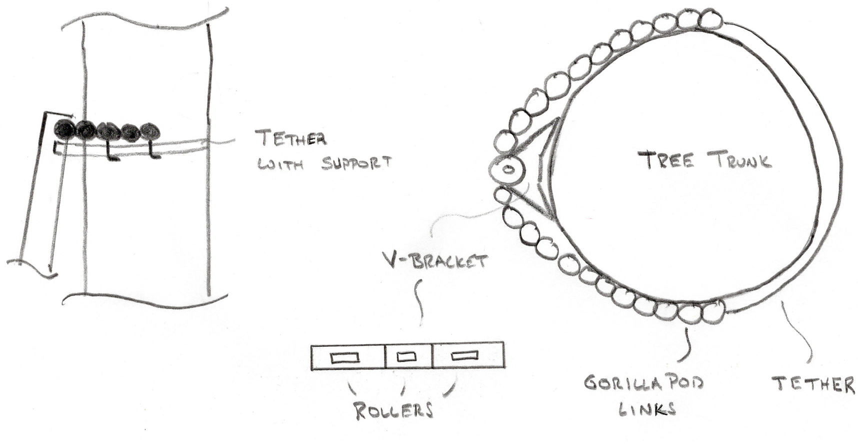


Figure 11.11: Concept Sketch for Gooseneck tubes and V-bracket with internal rollers

GorillaPod Prototype

Inspired by the physical presence of a GorillaPod tripod, a quick prototype was constructed to test the working principles of the end support concept. The available tripod was taped to the end of a wooden broom handle and tested against the side of a living tree.

The quick test revealed that while the pods did not roll as the pole was moved vertically up and down the tree, they did aid in keeping the end of the pole in contact with the tree trunk. The flexible nature of the ball and socket joints allowed for the end support to self adjust to variations in the tree trunk shape and diameter.

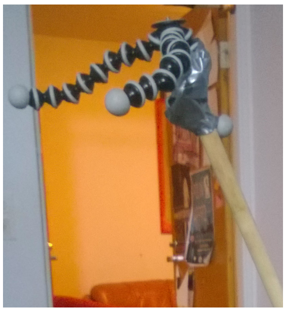


Figure 11.12: GorillaPod end support mock up

Pole to AMD Connection

If a long extension pole is to be utilized as a solution to raise the AMD, then some thought would be required on concepts for attaching the AMD to the end of the pole. The original application of the long poles that provided the inspiration for the solution path include the connection of tools or communication equipment to the end of the pole. Therefore a natural solution path was the development of such a connector for the AMD and its mount.

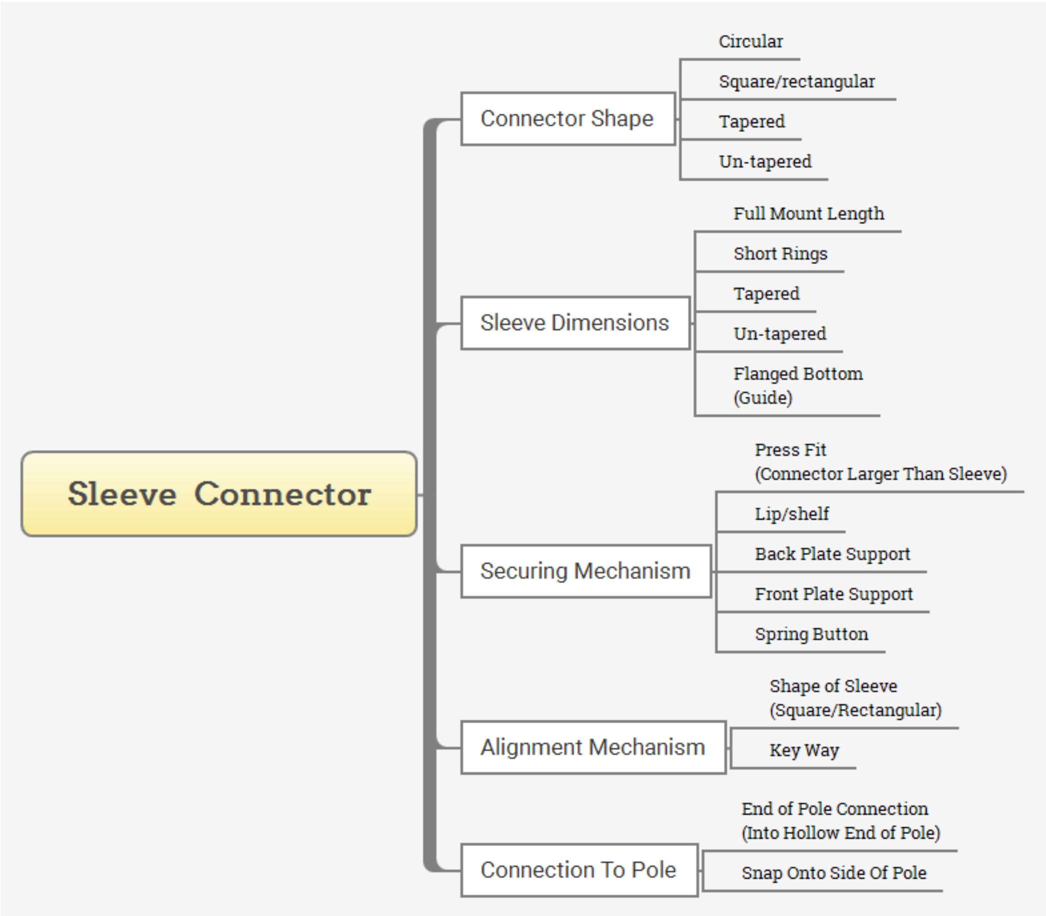


Figure 11.13: Concept classification tree - Sleeve Connector

The connection of the end of the extension pole to the connector would be adapted to match the connection mechanism already in place for the procured extension pole; with common mechanisms including twist locks, spring buttons, and threaded connections.

The majority of concepts developed revolved around a peg and sleeve connection - termed the ‘sleeve connector” - for the connector to AMD attachment, such as the concept depicted in figure 11.14, with the peg portion envisioned as part of the connector. The peg is tapered for the purpose of reconnecting the end of the pole to the mount with the intention of device retrieval. The sleeve is incorporated into the construction of the mount.

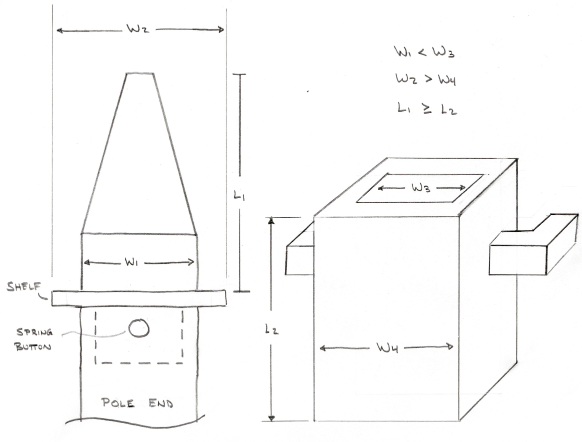


Figure 11.14: Pole connector concept sketch

In application, the AMD and mount sit on top of the “sleeve connector”. In the presented concept sketch they are supported by a shelf. Gravity holds the mount onto the shelf, while the square shape of the sleeve aligns the mount with the pole.

As the concept was further developed through the internal search, the shape of the peg and the sleeve were explored. This lead to the generation of a promising concept for the securement of the mount to the connector through the use of a press fit between the peg and sleeve.

11.2.2 Attach Device

The internal search for solutions to the second critical subproblem of “attach” device focused on attachment methods that would also facilitate the retrieval of the AMD. The search for solutions through concept generation first looked to the overall method of attachment, before exploring the type of mount that would facilitate the attachment mechanism.

Inspiration was drawn from the methods of attachment discovered through the tree hunting equipment covered in section 11.1.1 and the dynamic loop principle of the safety lines used in tree hunting - displayed in the one-stick climbing method.

Loop of Material

The title ”Loop of Material” was adopted as a neutral term to encompass the different types material that are available to secure a mount or AMD to a tree trunk. In general the term is meant to include metal wire, nylon webbing, and rope.

The solutions classified under this branch of the concept tree center on tying the AMD to the tree trunk - either directly or via a mount. They differ in the loop of material being static, with the AMD being hung from a pre-set loop; or dynamic, where the size of the loop is reduced to tighten around the tree trunk. The following section will focus on this branch of the concept classification tree displayed in figure 11.15.

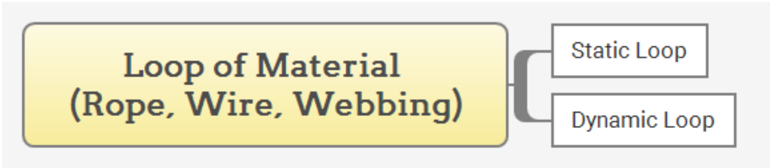


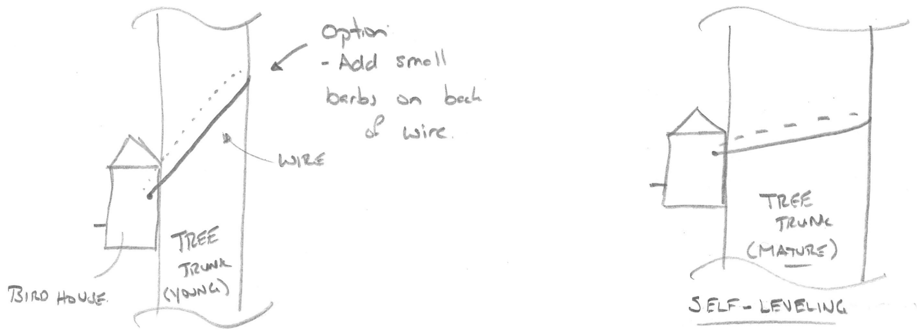
Figure 11.15: Concept classification tree - Loop of Material concept branch

Static Loop

Static loop refers to the concepts that utilize a fixed length of material - rope, nylon webbing, or wire - to secure the AMD to the tree. The most prominent of the static loop concepts is referred to as the “birdhouse wire” concept.

Developed while brainstorming with a colleague, and based off a childhood story of setting birdhouses directly to the trunk of trees with their grandfather, the “birdhouse wire” uses a simple piece of wire to secure a wooden backed mount (wooden box) to the tree trunk. The loop of wire is intentionally made much larger than the diameter of the tree trunk, so that the payload rests vertically lower on the tree trunk than the top of the loop of wire - thus the wire sits on a diagonal. As the tree grows and the trunk increases in diameter, the loop of wire self levels the wooden box.

As the loop of wire is required to be larger than the diameter of the tree trunk, it is possible for the wire to be set at the base of the tree and raised up the tree trunk with the AMD.



(a) “Birdhouse wire” on young tree (b) “Birdhouse wire” on mature tree

Figure 11.16: Concept sketch of ”Birdhouse wire”

Dynamic Loop

Dynamic loop incorporates solutions that attach the AMD to the tree through the action of tightening a loop of material. The path is split by two branches, noose concepts and tightened loop concepts. Like the static loop, these loops of material would be tied around the tree trunk prior to raising the AMD.

Inspired by the safety lines employed by tree hunters, noose concepts involved a loop of material with a bite (loop) in one end of the line, with the other end of the line going through that bite, forming a loop that can be made larger and smaller. Concepts would differ on the placement of the AMD on the loop and methods of tightening the loop.

Tightened loop concepts were attachment solutions that consisted of shortening a loop of material that was tied around the circumference of the tree trunk; one end would be attached directly to the AMD or the AMD's mount, and the other would be set into a lock or tightening mechanism on the opposite side of the AMD or the mount.

Through a variety of tightening and locking mechanisms the loop would be tightened and locked in place. Concepts for tightening mechanisms included direct pull chords - inspired by yardwork pole tools -, the release of a counter weight, and electric motors.

Field Tests - Loop of Material

To assist with the development of concepts classified under the loop of material solution path, simple field tests were conducted to explore the physical behaviour of loops of material tied around a tree trunk. Field tests were conducted with nylon webbing and static[1] cord (or rope[2]) in the static loop and noose(under dynamic loop) configurations. Full details of the tests are available in appendix 5.

To conduct the tests, the loops were tied around a live tree with a weighted bag attached by a carabiner to act as the payload. A payload of 3.7 pounds (1.7 kg) was used to mimic the weight of the AMD. The payload would be manually supported with the loop of rope and raised to head height. Once the payload and loop were in position for the specific test, the payload would be dropped and left to free fall to simulate a potential AMD installation. After the first round of tests, that examined loop setups with little clearance between the loop and tree trunk, a second round of tests were conducted to further explore the limits of how large a loop could be employed in relation to the size of the tree trunk - or in other words, how much slack could be in the system.

The goal of the first round of field tests was the exploration of the physical interactions between the loop of material and the trunk of the tree. A key question was how tight to the tree did the cord or webbing have to be tied to the tree for the payload to be secured, and how would the inverse effect the ability of the loop of material to secure the payload. The tests resulted in the knowledge that for a tolerance between the tree trunk diameter and loop diameter judged to be necessary to allow the loop of material to be pushed up the tree trunk would not interfere with the loop securing the payload. This validated the use of a loop of cord or webbing as a viable solution path.

The second round of field tests looked to expand upon the the results of the first, by asking the question of how large a loop in comparison to the tree trunk diameter would secure the payload. Three rounds of tests with increasing loop sizes determined that even in the extreme case of the loop diameter being 279 percent larger than the diameter of the tree (a 72.9 cm diameter loop on a 26.1 cm diameter tree trunk), that a static loop would secure the payload. At this point the loop could not be additionally increased without the payload reaching the ground due to height restrictions in the initial placement of the loop.

[1]Static refers to rope that is designed to not stretch under load.

[2]There is an overlap in the definitions of cord and rope. Cord is defined as having a diameter of 1/16 inch to 3/8 inch (1.6 to 9.5 mm); rope a diameter of 3/16 inch to 5 inches (4.8 to 127 mm)(Soles, 2004, pg. 22)

Figure 11.17: Static loop drop test - 73 cm diameter loop on 26 cm diameter tree trunk

The placement of the payload (or AMD) in relation to the tree trunk prior to it being released to free fall was another aspect of concept examined throughout the field tests. The payload was deployed in two configurations. The first configuration had the payload placed in direct contact with the trunk of the tree prior to being released, with the loop of material supported away from the tree trunk. The second configuration had the payload pulled away perpendicular from the tree trunk at a distance that caused the back of loop of material on the opposite side of the tree trunk to be in firm contact with the trunk of the tree.

The first configuration resulted in the payload falling vertically until the loop of material made contact with the tree trunk. The result was emphasized in the second round of field tests, as the larger loops would drop a noticeable distance before contact was made with the trunk of the tree and the payload was secured.

The second configuration with the payload pulled away from the trunk of the tree would result in no perceivable vertical descent on the part of the loop of material. The payload would fall down and towards the tree trunk, with the back of the loop of material in contact with the tree trunk acting as the pivot point. The payload would be secure once it made contact with the tree trunk, coming to rest.

These observations confirmed the need for installation steps when implementing a loop of material as the attachment mechanism. Similar to the second placement of the payload with respect to the tree trunk, the payload should be pulled away from the trunk of the tree until the loop of material is in contact with the tree trunk. Then the payload can be lowered vertically downward and horizontally towards the tree trunk in an arc. This would effectively "hang" the device on the tree trunk.

The observations from the field tests would further the development of the loop of material

(a) Slack measurement of 15 cm

(b) Payload pulled away from tree trunk

(c) Payload secured by static loop

Figure 11.18: Static loop drop test - payload configuration 2

solution concepts for the critical subproblem of “attach” the device.

AMD Mount

Concepts for an AMD mount were developed in conjuncture with the concepts for securing the mount to the tree trunk. Mount concepts were distinguished by their construction material and the method of interaction with the trunk of the tree.

Construction from square or circular hollow tubing showed promise as a solution path for its natural integration with the end of pole connection concepts outlined in section 11.2.1. The modification of existing tree climbing sticks provide the potential for the quick adaptation of a proven design for the attachment to irregular tree trunks.

The mount concept sketch presented in figure 11.20 was developed together with a dynamic loop attachment concept, where a rope is placed around the trunk of the tree and once tightened is locked by a set of cam cleats. The shape of the mount is based off a tree hunting gear stand described by the manufacturer as bark teeth. The addition of the hollow square tube behind the mount is an example of a receiver sleeve for an end of pole connector.

11.2.3 Retrieve Device

The internal search for solutions to the subproblem of “retrieve” device was conducted after the exploration of solutions for the subproblems of “raise” and “attach” device, as it was not designated a critical subproblem. As such, the solution concepts were primarily developed with their solution principles in mind.

For the solution paths of elevating the AMD with a long pole and attachment via a loop of material, AMD retrieval concepts centred on the reconnection of the pole connector to the

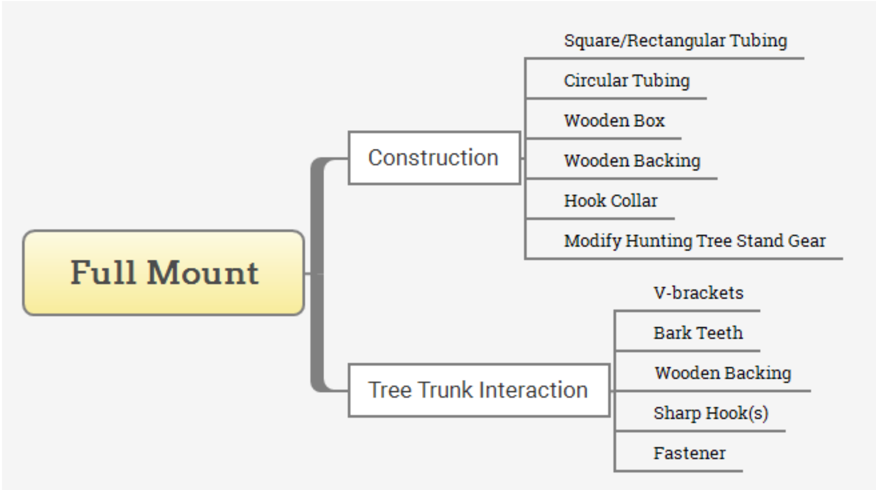


Figure 11.19: Concept classification tree - Full Mount

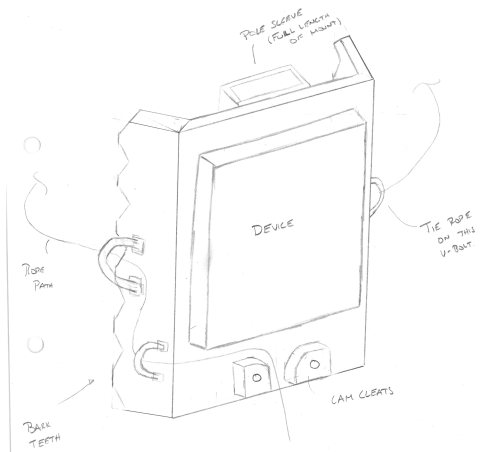


Figure 11.20: Mount concept sketch

sleeve on the mount and the reversal of the attachment method. Once the mount is detached from the tree trunk, it is lowered to the ground via the pole.

For a static loop attachment the mount would be raised vertically to disconnect the “birdhouse wire” from the trunk of the tree, thus “un-hanging” the AMD. Dynamic loop removal consists of disengaging the locking mechanism or the severance of the loop material - an option also available for a static loop.

12 Analysis and Results: Concept Generation Results

The search for solutions concluded when there was confidence that the entire solution space had been explored and that the concepts generated would result in an installation method that would meet the customer's needs.

The result of the external and internal search was the generation of a large number of concept sketches that contained the solution fragments to the subproblems that were identified as critical to creation of a successful concept. The concept fragments that these sketches represent are collected, organized, and communicated through the use of concept classification trees.

Upon review of the concept classification trees, the most promising solutions are selected and combined into a complete concept that is able to meet the customer needs for an AMD field installation method that is capable of both temporary and permanent installations.

Prior to recommendation to the customer, a final rough prototype was constructed to verify the functionality of the selected combination of concepts.

12.1 Concept Classification Trees

An intended result of the search for solutions is the generation of a large number of solution principles to the subproblems identified in section 10.2, mostly in the form of concept fragments. The combination of these solution fragments results in the formation of a complete solution concept.

The collection, organization, and communication of these concept fragments is aided through the use of the concept classification trees - the exerts of which have been used throughout the previous sections to illustrate the search for solutions. The concept classification tree organizes the the solutions into distinct classes, highlighting the independent categories of the solution paths for the examined problem. (Ulrich, 2003).

The solution paths are reviewed for the separate concept classification trees developed for each of the critical subproblems.

12.1.1 Raise Device

While the internal search highlighted concepts related to the use of long extension poles, a number of other solution principles were explored for the subproblem of "raise" device. The division of concepts was based on the simple question of how the AMD can be raised to the installation height. The first - and most important from the customer's point of view - division of concepts occurs with respect to the location of the operator during the installation; is the AMD carried into the tree by the operator or is it raised remotely from the ground.

RAISE WITH INSTALLER

Concepts that required the AMD to be carried by the operator are broken down by how the operator reaches and is supported at the installation point, whether through physically climbing the tree or being supported by a platform at height. Personal climbing techniques consist of the arborist climbing techniques explored in section 5.2.1. Installation platforms refers to concepts that provide an elevated working platform to support the operator at the installation height, while “from air installations” refer to methods of supporting the operator from the sky.

RAISE FROM GROUND

Concepts that facilitate the elevation of the AMD from the ground are classified based on how they propose to raise the AMD. It was determined that the AMD could be pushed, flown, pulled, or carried up a tree.

The “push it up” branch contains concepts that support the AMD from below, with the primary concepts being the use of the long extension poles described in the external search in section 11.1.2.

The strongest concept from the “fly it up” branch was the use of a drone to elevate the AMD to the installation point. Other methods were explored to ensure the complete exploration of the solution space.

The “pull it up” branch explored concepts that utilize a line set in the tree to raise the AMD. Concepts are divided by how the AMD is raised up the line. The pulley branch sees the AMD fixed to the end of a line set through an installed pulley point in the tree. The AMD is raised as the free end of the line is pulled downward by the operator. Line climbers designates concepts where the AMD travels upwards along a set line that remains stationary . The spool reel in branch explores concepts where the line is retracted into a spool that is attached to the mount or AMD, shortening the line and raising the AMD.

Solutions grouped under the “carry it up” branch of the classification tree seek to piggy back the AMD on an entity that possess the ability to climb the tree trunk. The branch is dominated by the tree climbing robots discussed in section 5.2.5 and the construction of tree trunk climbing machine.

12.1.2 Attach Device

The attach device concept classification tree depicted in figure 12.2 explores the solution fragments for physically securing the AMD to the tree. The dominate solution branches of “loop of material” and “mechanical fasteners” were described in the search for solutions in sections 11.1.3 and 11.2.2 respectively. Other methods of attachment explored include the use of adhesives, the modification of clamps, and the penetration of the tree trunk through the use of hooks.

The “clip to mount” and “hang from line” are concept branches that consist of the indirect attachment of the AMD to the tree that support the “pull it up” branch of the raise device concept classification tree.

The ”ground pulley tie off” branch encompasses the concept of supporting the AMD by a pulley line that is secured at ground level. This would facilitate the retrieval of the device.

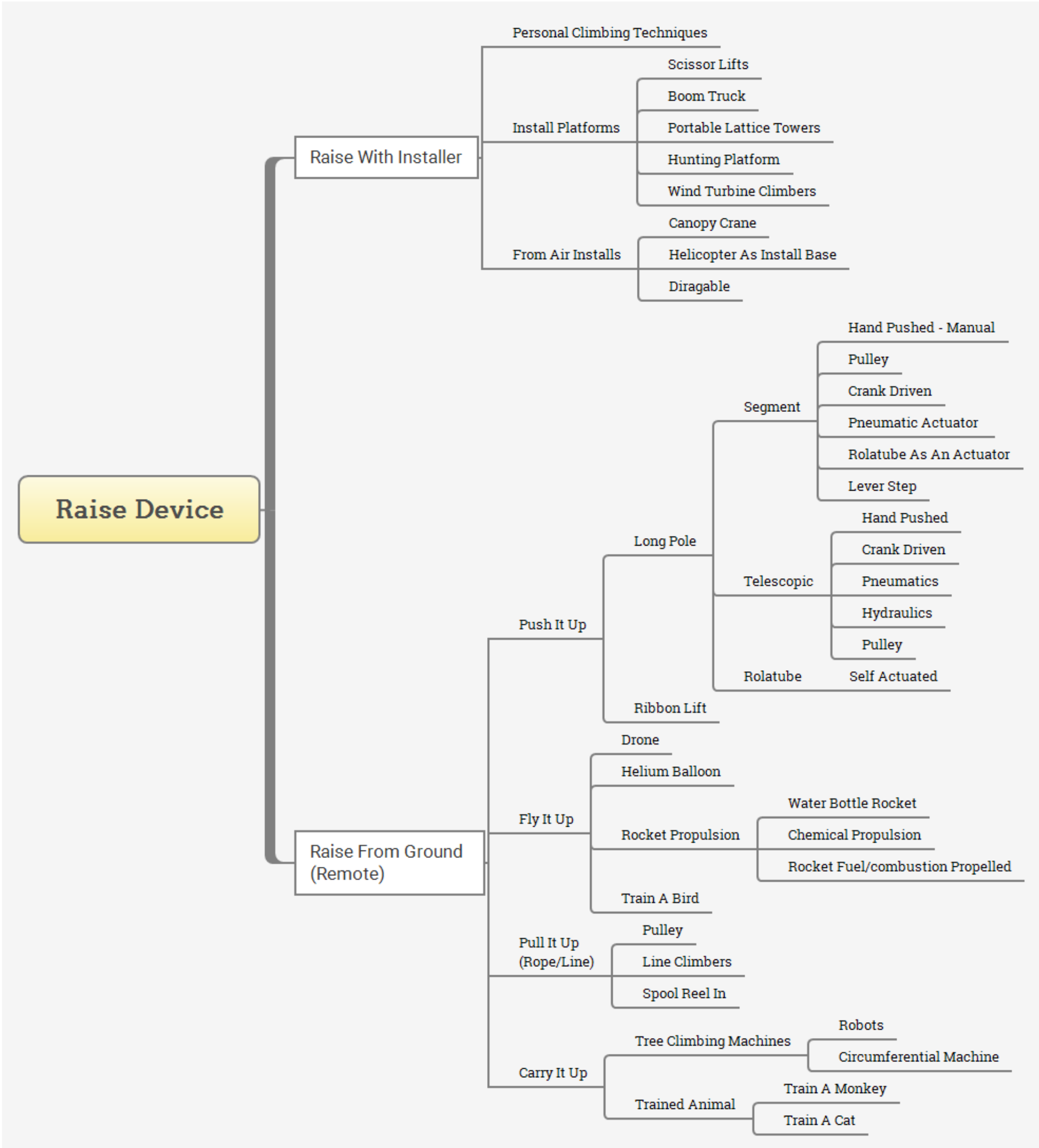


Figure 12.1: Concept classification tree - Raise Device

12.1.3 Retrieve Device

The application of a concept classification tree to the subproblem of "retrieve" device lead to the further refinement of the problem into two additional subproblems; the detachment of the AMD from the tree and the subsequent need to support and lower the AMD.

The "detach device" concept tree branch in figure 12.3 communicates the two philosophies for unsecuring the AMD from its installation point; the detachment of the entire installed assembly from the tree, consisting of the AMD and the mount; or the disconnection of the AMD from the mount, with the mount remaining in the tree. Methods for the first option are dependent on the fastening mechanism selected as the solution to the "attach" device subproblem, and generally involve the reversal of the fastening mechanism. "Detach from mount" concepts are independent of the chosen fastening mechanism.

Once the AMD has been set free from its securement to the tree trunk, it must be supported

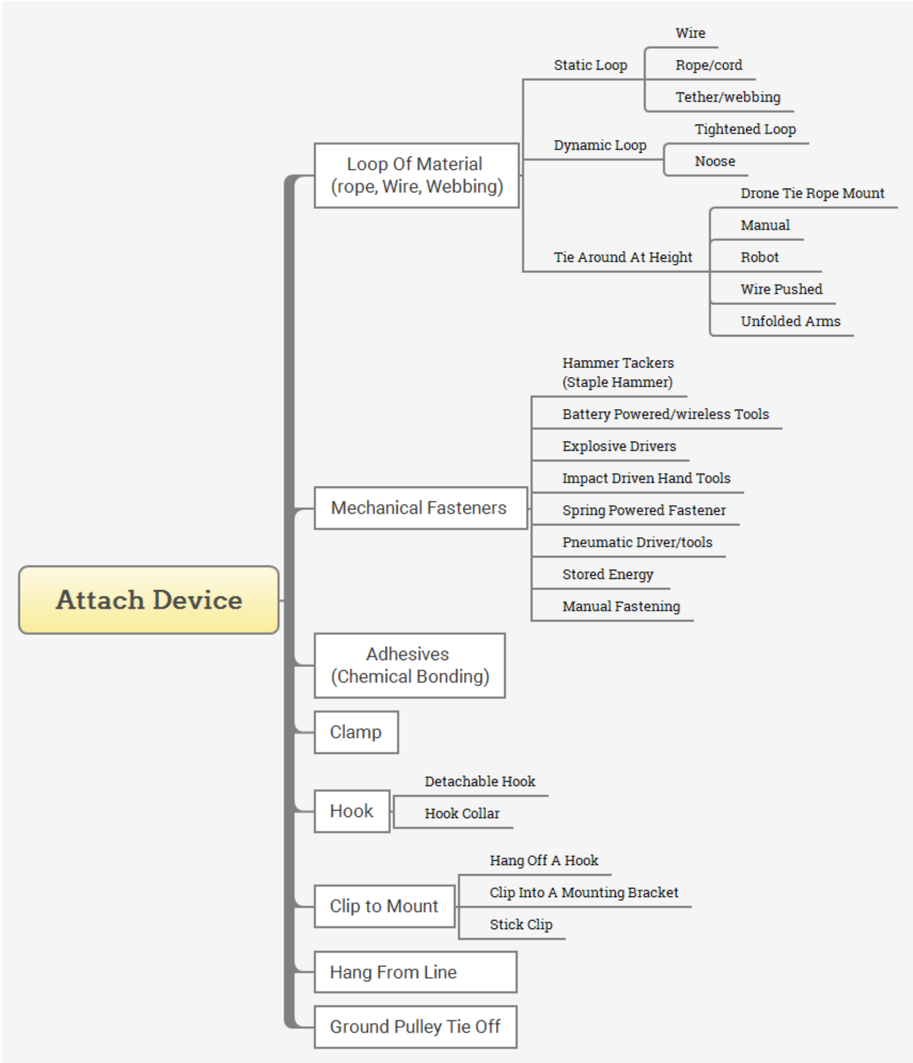


Figure 12.2: Concept classification tree - Attach Device

to prevent damage on its descent to the ground. The collection of concepts for the support of the AMD are both related and independent of the solution selected for elevating the AMD.

12.2 Final Concept Description

The combination of the strongest concept fragments lead to the creation of two complete solution concepts. Solution concepts were selected for both the primary goal of a technique for the permanent installation of an AMD and the additional goal of a technique for the rapid, temporary installation of AMDs for diagnostic purposes. The difference between the two would be the selection of the concept fragment for the “raise” device subproblem.

The general final concept for both installation targets is the hanging of the AMD to the trunk of the tree from the end of a long, carbon fibre pole. The AMD is supported by a static loop of braided wire through the use of a wooden box mount. To facilitate the hanging of the AMD, the mount is connected to the pole via a press fit sleeve connector secured to the end of the pole. The gravity based press fit ensures that the mount will only detach from the pole

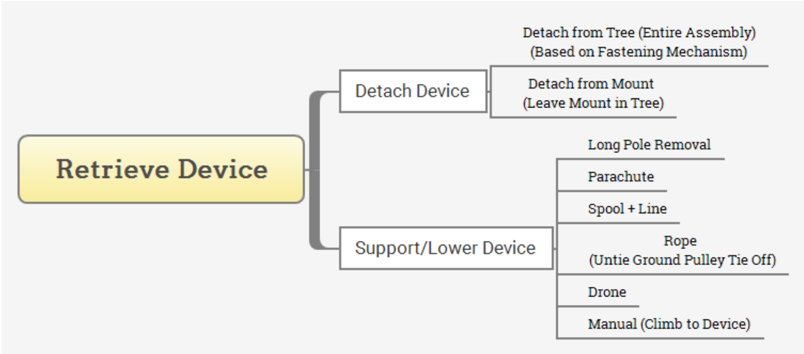


Figure 12.3: Concept classification tree - Retrieve Device

connector when it has been secured to the trunk of the tree and its weight has been transferred to the tree trunk through the static loop. The retrieval of the AMD is accomplished through the reconnection of the pole end to the mount and a reversal of the "hanging" of the static loop of wire.

The two developed final concepts differ in the selection of the type of carbon fibre extension pole utilized, and the additional details required for the application of each type of pole.

The concepts are presented with respect to the solutions to the subproblems of "raise", "attach", and "retrieve" device.

12.2.1 Raise Device

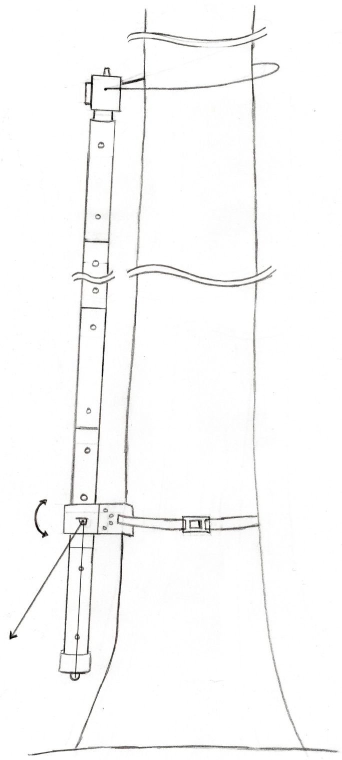
The solution to the subproblem of "raise" device is the defining characteristic of the two developed solution concepts. Of the generated concept fragments that allow for the AMD to be installed without the operator having to physically climb the tree, the adoption of a long extension pole was selected as the concept that would best meet the customer's needs.

The long pole solution path presented two primary solution paths in the type of long pole to be utilized, segment and telescopic. Their use was selected based on the elevation required for the installation. For elevations of a greater height than 30 feet (9 meters), the segment pole was the preferred concept due to its proven rigidity and the structured steps of its elevation. For installation elevations of less than 30 feet, the telescopic pole was the preferred concept due to its compact nature and simplicity of use. In both cases the material selected for the poles is carbon fibre, due to its physical properties high rigidity, low density, and durability.

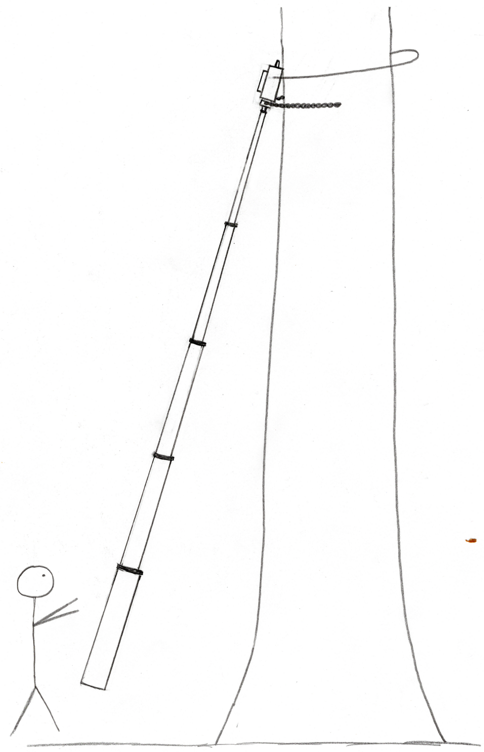
The two developed concepts are titled based on the type of pole implemented and their method of operation.

Pulley Operated Segment Pole

The utilization of a carbon fibre segment pole adapts the working principles exhibited by the military communication masts explored in section 12.2.1. The complete setup of the concept is displayed in figure 12.4a. The setup consists of the "rocker" tree mount as the ground support for the pole. There is no middle of the pole or end of the pole support. The wooden box mount sits atop of the pole supported by the sleeve connector, which is depicted in the figure as extruding past the top of the mount. The static loop of wire for the "birdhouse wire"



(a) Segment extension pole with tree mounted pulley (“rocker”)



(b) Hand held telescopic pole

Figure 12.4: Raise device solution concepts

attachment concept is shown encircling the tree trunk.

A key component of the concept is the inclusion of the “rocker” ground support, that was previously described in figure 11.9 on page 69, as it performs a number of functions. First, it provides a secure base for the ground support of the pole. Second, the lockable pivot point that is the source of the concepts name allows the operator to maintain contact between the wooden mount and the trunk of the tree throughout the elevation of the pole. This ensures stability at the top end of the pole and ensures that the static loop of wire maintains clearance with the tree trunk through the elevation process; though in application it may be possible to raise the segment pole straight up. The pivot point also facilitates the hanging of the AMD from the static loop of wire. Finally, the “rocker” tree mount serves as the working platform for the erection of the pole through the use of the integrated pulley.

In operation, the set up of the installation system begins with the installation of the “rocker” onto the trunk of the tree selected for installation. The “rocker” is secured via nylon strapping, with a v-bracket providing the interaction surface with the tree trunk. Once secured, a pole segment is placed into the “rocker”, with the bottom end of the pole placed in the pipe shoe attached to the pulley system. Before the segment pole is erected, the sleeve connector is attached to the top end of the first pole segment, followed by the setting of the wood box mount on top of sleeve connector. To complete the setup, the static loop of wire is placed around the tree trunk and attached to the wooden mount.

The pipe shoe and pole are then raised through operation of the pulley, whose use can be aided through the use of a hand jumar. This would provide a handle for the operator other than the raw rope of the pulley, and provide a self locking mechanism for the pulley rope. Once the pulley is fully raised a locking pin is inserted into the hole present on the bottom pole segment, above the top edge of the “rocker” mount. Once secured, the pipe shoe is removed from the bottom of the pole and the pulley is lowered. The next pole segment is attached to the bottom of the pole supported in the mount, with the other end placed in the pipe shoe. The locking pin is removed and the process is repeated until the AMD and wooden mount reach the desired installation height. During the erection of the segment pole, it may be required to unlock and adjust the angle of the rocker mount depending on the shape of the tree trunk.

Once the installation height is reached, the AMD is attached to the tree trunk by hanging it from the static loop of wire. To achieve this, first the pulley line is locked in place with a stopper knot or the hand jumar, while the pivot point of the “rocker” is unlocked. The pole is then angled away from tree trunk until the the back of the static loop of wire is engaged with the tree trunk. The segment pole is lowered via the release of the pulley, and allowed to angle back towards the tree trunk as the wooden mount begins to sit on the static loop of wire. As the AMD is secured to the tree, the continued lowering of the pole removes the pole end of the sleeve connector from the wooden box mount.

The carbon fibre segment pole is retracted by a reversal of the erection steps.

Hand Held Telescopic Pole

The hand held telescopic pole is a prime example of the “less automate, more obvious” philosophy expressed in the second iteration of the mission statement provided in section 9.1. The setup depicted in figure 12.4b includes the same wood box mount, static loop of wire, and sleeve connector setup as described for the segment extension pole shown in figure 12.4a. A GorillaPod end support is included at the top end of the pole to provide a continuous contact point for the end of pole and the trunk of the tree. The ground support of the pole is provided by the operator.

Set up of the system begins with the carbon fibre telescopic pole fully retracted - as it would have been for transportation. The sleeve connector and wood box mount are attached in turn to the end of the pole, which is then placed directly against trunk of the tree. Setting of the static loop of wire to the wood box mount and around the tree trunk completes the setup.

To raise the end of pole assembly, the telescopic pole segments are extended and locked by hand, beginning with the top segment. As the pole is extended the wood box mount and GorillaPod end support are kept in constant contact with the trunk of the tree; primarily to support the end of the pole, while also ensuring clearance between the loop of wire and the trunk of the tree.

Once at the desired installation height, the AMD is attached to the tree through the steps depicted in figure 12.5, whereby the pole is pulled back away from the tree trunk until the back of the static loop of wire is engaged with the trunk of the tree. The end of the pole is lowered in a downward arc angled towards the center of the tree trunk. Once the AMD is secure, the end of the telescopic pole is lowered through the retraction of the pole segments.

12.2.2 Attach Device

The concept fragment chosen to solve the critical subproblem of "attach" device is the use of a static loop of metal wire, titled the "birdhouse wire" concept. First depicted in figure 11.16 on page 73, the "birdhouse wire" consists of a single strand of wire wrapped around the trunk of the tree and attached to both sides of the wood box mount, as shown in figure 12.5. The loop is intentionally made larger than the diameter of the tree trunk to facilitate the raising of the AMD and to prevent harm to the tree from tree strangulation.

The attachment of an AMD through the use of the "birdhouse wire" static loop is depicted in figure 12.5, with the use of a telescopic pole for the example. In the first stage, the "birdhouse wire" is provided enough clearance from the trunk of the tree to avoid contact while the AMD is being raised by the pole. In the second stage, where the AMD is at the installation height, the "birdhouse wire" is engaged with the tree trunk when the operator pulls the pole radially away from the trunk of the tree. Once engaged, the third stage has the operator lower the end of the pole in a downward arc towards the tree trunk. This "hangs" the wood box mount on the static loop of wire and allows for the sleeve connector to disengage from the mount at the beginning of the fourth stage, where the pole is retracted and the AMD is installed in the tree.

Despite the simplicity of the "birdhouse wire" concept, there are a number of details to be considered in the application of a static loop of wire for the attachment of an AMD to the trunk of a tree. The key details include the mount type, the loop material and construction, and if any support is to be provided for the loop. The self levelling mechanism of the concept needs to be taken into consideration when selecting a mount type. Braided wire is the current selected loop material, as its flexibility increases the contact surface area with the tree trunk compared to a stiffer solid wire. In the ideal situation, the wire is stiff enough to not require any external support to maintain a clearance from the surface of the tree trunk. In practice, it is possible to pre-torque the wire to prevent it from vertically lowering from the horizontal under its own weight. In the instance where a smooth wire is unable to reliably secure the mount to the trunk of the tree, it is possible to utilize a barbed wire.

The use of a gravity based, press fit sleeve connector also greatly simplifies the application of the "birdhouse wire" attachment concept. As the wood box mount is held by gravity, once the wire has been secured to the trunk of the tree, the sleeve connector naturally disengages from the mount as the pole is lowered. Of even greater importance is the fact that the sleeve connector would not disengage from the mount unless the mount is secure to the trunk of the tree. If it is not secured, than the mount will remain fixed to the end of the pole via the sleeve connector, thus preventing premature detachment from the end of the pole.

12.2.3 Retrieve Device

The method of retrieval of an installed AMD was developed and chosen based on the selected concept fragments for the critical subproblems of "raise" and "attach" device that were previously described. The selection of the "birdhouse wire" concept in particular influenced the concept for retrieval, as it provided a simple path for the reversal of the attachment mechanism. The selection of a long extension pole concept for the elevation of the device provided a direct path for the support of AMD during the retrieval process. Therefore, the retrieval concept is the reattachment of the long pole to the wood box mount

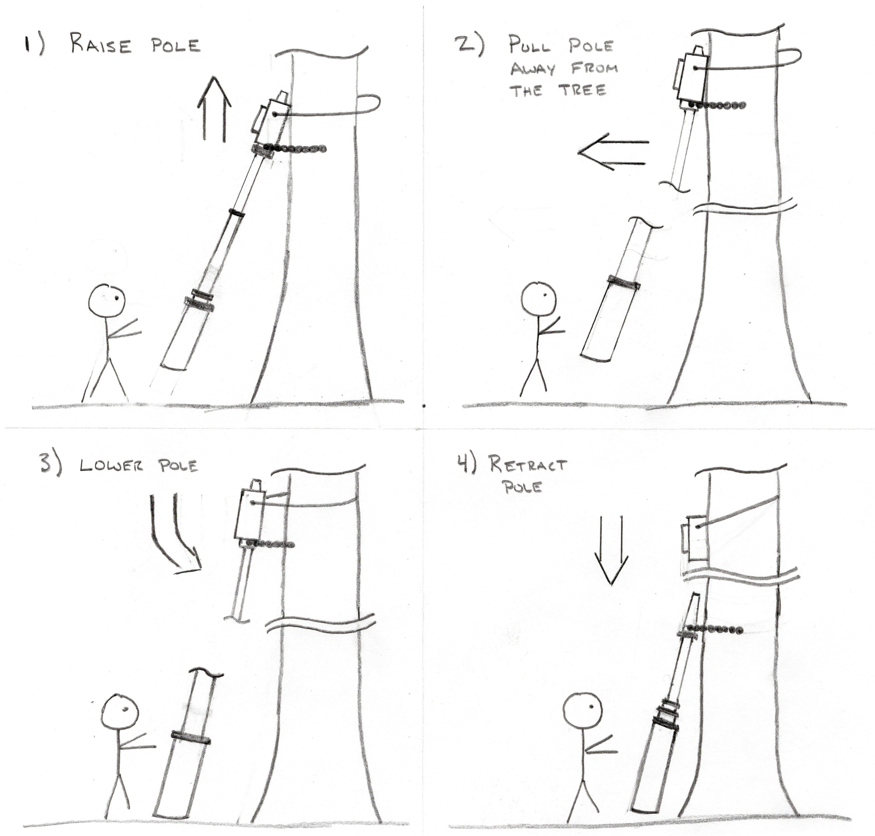
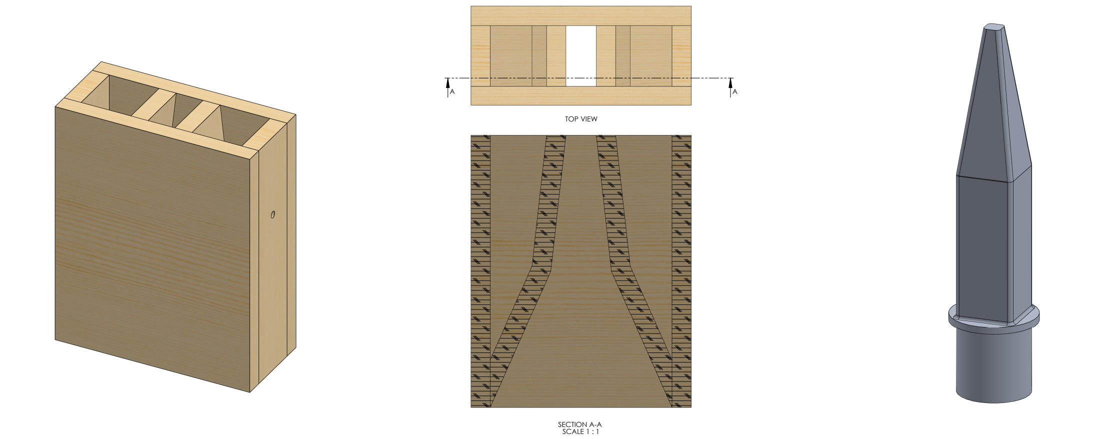


Figure 12.5: Birdhouse wire attachment steps with telescopic pole

and the disengagement of the static loop of wire from the trunk of the tree.

The concepts for the mount and pole connector were developed for the retrieval of an AMD through the reconnection of the sleeve connector at the installation height. The taper on the top the sleeve connector shown in figure **??** serves two functions. One is to facilitate the reconnection of the connector to the bottom of the mount and the second is to provide the press fit that secures the mount to the connector. The cross section of the wood box mount provided in figure 12.6b depicts two stages of internal tapered guides. The top, narrow taper is designed for the before mentioned press fit with the sleeve connector. The bottom, wide taper is to act as a receiver flange for the sleeve connector to aid in the reattachment of the pole to the mount.

In application, the steps for the retrieval of the AMD are those shown in figure 12.5 conducted in reverse. In stage four, the sleeve connector is inserted into the bottom of the wood box mount. The end of the pole is moved up and radially away from the tree trunk by the operator in stage three, before being moved back towards the tree trunk horizontally to disengage the static loop of wire in stage two. In stage one, the AMD is lowered to the ground as the pole is retracted.



(a) Mount - Wood box mount (b) Mount - Wood box mount cross section (c) Sleeve connector

Figure 12.6: Concept details

12.3 Birdhouse Prototype

Before the results were presented to the customer, a rough prototype was constructed to test the application of the “birdhouse wire” concept for the attachment and retrieval of an AMD at the end of a pole. The physical behaviour and the limits of the static loop of wire were examined, in addition to tests to determine if the static loop could be installed and retrieved from the end of the pole as envisioned in the developed concepts. Test results were immediately communicated with the customer.

As the concept has its origins in the setting of birdhouses, a birdhouse was modified to represent the wooden mount. The simple modifications of an attached harness eye bolt and a wooden block with a hole drilled through its center, allowed for additional weight to be attached to the birdhouse and for the birdhouse to sit on the end of a pole, respectively. A broom handle was utilized as a pole for the tests. Tests were conducted with 2 mm extruded galvanized steel wire (smooth) and 3 mm braided galvanized steel wire. A weight was placed inside of the birdhouse to give the assembly a weight of 7 lbs (3.2 kgs), approximately twice the weight of an AMD. Additional weights were clipped to the harness eye bolt to increase the weight to 10 lbs (4.5 kgs).

Tests were conducted on two trees of different trunk diameters and bark roughness, a 9.5 inch diameter smooth barked tree and 16 inch diameter rough barked tree. As the tests were conducted with the purpose of the verification and communication of the validity of the installation method, focus will not placed on the exact measurements of the loop size or the surface friction of the tree bark at this time. The unknown and wide range of tree variability encountered in the operating environment of various remote rainforests justified the general nature of the tests.

Once installed on the loop of wire, the birdhouse was struck repeatedly to test the reliability of the installation, after which the birdhouse would be removed from the tree through the reconnection of the pole with the bottom of the tree trunk and the execution of the retrieval steps outlined in section 12.2.3. At the conclusion of the installation tests, the birdhouse was left installed in the tree to allow for the observation of the effects of time and weather, such as rain and wind, on the success of the installation. The birdhouse was inspected at one and three month intervals with no detachment observed.

Figure 12.7: Birdhouse prototype materials

The first round of tests were conducted to test the general installation method of setting the loop of wire at the base of the tree trunk, the raising of the mount (simulated by the birdhouse) on the end of a pole, and the “hanging” of the mount on the tree trunk from the end of the pole. Initial tests were conducted with the 2 mm extruded galvanized steel wire on a smooth barked tree. The length of the loop of galvanized wire was set to provide the clearance necessary to avoid unintentional interaction with the trunk of the tree throughout the raise device stage of the installation process. The tested installation procedure of “hanging” the birdhouse is depicted in figure 12.8. Upon conclusion of the installation and impact tests, the birdhouse remained firmly secured to the trunk of the tree. The loop of wire did not require external support to prevent the wire from descending below the horizontal under its own weight. The birdhouse was then removed through the reversal of the installation steps.

The second round of tests were conducted to investigate the upper limit of the clearance between the loop of material and the diameter of the tree trunk that would secure the birdhouse to the tree. Depicted in figure 12.9, the loop was set to a size far beyond the necessary clearance to avoid unintentional contact with the trunk of the tree. When pulled away from the tree trunk, the measurement from the nearest edge of the tree trunk and the back of the birdhouse was 17.7 inches (45 cm). In addition to testing the upper limit of a functional loop of wire, the large discrepancy between the diameter of the tree trunk and the loop of wire also simulated extreme cases of tree trunk diameter variability between ground level and the installation height.

The conclusion of the second round of tests demonstrated the ability of a very large loop of wire to secure the birdhouse to the tree. Impact tests resulted in the detachment of the wire from the tree trunk, although the wire would reattach itself a few centimetres below the original installation point. Upon inspection the cause was determined that the majority of the extruded wire was not in contact with the trunk of the tree; the loop of wire was supported by only a handful on contact points with the bark of the tree. It is important to note that the large loop of wire did not require additional support to prevent the wire from descending vertically under its own weight, therefore support of the loop was unnecessary.

(a) Birdhouse raised up against the tree trunk

(b) Setting the birdhouse

(c) Attached birdhouse

Figure 12.8: Birdhouse tests with 2mm galvanized steel wire

The third round of tests were conducted to investigate the properties of the 3 mm braided galvanized steel wire compared to the 2 mm extruded galvanized steel wire. The loop of wire was set to a similar size as that depicted in figure 12.8. Upon inspection the braided wire was observed to drop below the horizontal under its own weight. This was corrected by applying a pre-torque to the wire prior to its attachment to the birdhouse. Due to its flexibility, the braided wire provided more contact with the tree trunk when compared to the more rigid extruded wire. Upon conclusion of the installation, impact, and retrieval tests, the braided wire provided similar successful results to those observed in the first round of tests.

In review, the conclusion of the prototype tests revealed that the installation and subsequent retrieval procedures outlined in figure 12.5 are successful for low elevation installations. The self reattachment mechanism of the loop of wire in the event of unintended detachment was also established. The tests demonstrated the ability of the wire to support itself throughout the installation process, with the potential for the application of a pre-torque in the wire in instances where the utilized wire is of insufficient rigidity to support its own weight. No external loop support was necessary.

(a) Birdhouse raised up against the tree trunk (b) Setting the birdhouse

Figure 12.9: Birdhouse tests with 2mm galvanized steel wire

13 Reflection and Next Steps: Final Recommendations

The next steps of the project follow the final recommendations of the project; namely the implementation of the hand pushed telescopic pole concept for immediate field trials, followed by the detail design and construction of prototypes of the pulley operated segment pole concept. Field trials are likely to occur as part of RFCx's ongoing pilot project in Ecudor in 2017, where RFCx intend to install additional AMDs.

The Ecuador pilot has been described by RFCx as their testing laboratory, as the combination of the pilot area's close proximity to the city of Guayaquil and the cellular infrastructure available in the region make it an ideal place for testing. The close proximity to the city ensures the availability of equipment and raw materials for the construction of prototypes, while the cellular infrastructure reduces the elevation required for successful AMD installation - with sufficient cellular signal available from ground level. These characteristics make it the ideal place for field trials of the developed concepts and not a typical remote rainforest.

Prior the conclusion of the project, the final results are reflected upon with regards to the satisfaction of the goals of the project - as presented in the project mission statement and the interpreted needs of the customer - and the limitations inherent in the project.

13.1 Recommendations

Upon conclusion of the concept generation and prototype tests, it is recommended that the developed solutions be executed in separate phases to provide early test results from the use environment at a reduced cost of investment. The first phase would see the employment of the hand operated telescopic pole for installations at elevations of less than 30 feet (9 meters) to test the presented solution principles of the developed concepts. Successful implementation would provide RFCx with a new tool for the temporary installation of AMDs for the purpose of field diagnostic tests prior to the selection of permanent installation locations - the secondary goal of the project. The pulley operated segment pole concept would be implemented in the second phase for the the installation of the AMD at the current installation height of 60 to 70 feet (18 to 21 meters).

Phase one implementation allows for the determination of the functionality of the "birdhouse wire" solution for the attachment and retrieval of the AMD at the end of an extension pole. The simplicity of the design allows for the direct testing of the "hanging" attachment principle. Once established for the initial pole length of 20 to 30 feet (6 to 9 meters) the total length of the telescopic pole can be increased through the addition of modular extensions until the useful limit of the telescopic pole for installation is reached. It is anticipated that the limiting factors will be the flexibility in the pole and the physical effort required to support the the telescopic pole by hand at lengths greater than 30 feet.

At this point, phase 2 would commence with the implementation of the pulley operated segment pole, as described in section 11.1.2. The pulley operated segment pole is reserved for the second phase as it requires a greater investment in terms of detail design of the "rocker" tree mount, the pulley system, and a larger financial investment to obtain the raw materials. Experience obtained from tests conducted as part of the implementation of phase one, with regard to the performance of the "birdhouse wire" attachment and retrieval methods, will influence the continued development of the pulley operated segment pole concept.

13.1.1 Phase 1: Telescopic Pole Installation

The core goal of phase one is to conduct field tests to determine the viability of the solutions selected for the elevation, attachment, and retrieval of RFCx's AMD in the operational environment of a remote rainforest. Along with with the suitability of the installation and retrieval methods in general, tests are to be conducted to determine the height limit for which a telescopic pole is suitable for the installation and retrieval of a RFCx AMD.

For the initial implementation of phase one, it is recommended that a commercial telescopic carbon fibre pole be procured from the water feed pole window washing industry. Full carbon fibre poles are available in useful lengths ranging from 17.5 feet (5.3 meters) to 78 feet (23.7 meters). Despite the slightly higher cost of the full carbon fibre pole over the comparable composites, it is recommended that a full carbon fibre pole be procured to provide accurate results on its field operation.

While it is not the purpose of this report to recommend a specific supplier for the procurement of the telescopic pole, as similarities between manufactures places the emphasis on locally available suppliers, an example product would be the SLXII Full Carbon Fibre line supplied by Gardiner. As with many manufactures, this line of telescopic extension poles is modular in its addition of telescopic extensions. Therefore, RFCx would be able to begin testing with a 17.5 to 25 foot (5.3 to 7.6 meter) pole that provides a working reach of 23 to 30 feet (7 to 9 meters), at a cost of $230 to $303 USD. Based on the results of the initial field tests, additional telescopic extensions can be procured to a maximum length of 46.9 feet (14.2 meters), at a cost of $77 to $105 USD per extension. Dependent on the amount of initial financial investment available, the entire system can be purchased at a cost of $700 USD[1]. The weight of the entire system is 7.4 pounds (3.38 kg) and it has a contracted length of 5.7 feet (1.72 meters). (Gardiner Pole Systems Ltd, 2014).

One rational behind the adoption of a commercial water feed telescopic pole for the first stage of concept implementation is the low level of modification required to achieve a functional tool. The purchase of a commercially available pole removes the need for detailed design on the pole dimensions and the locking mechanism between pole segments. As the poles are designed for the attachment of end tools, the adoption of a sleeve connector would be designed to attach to the end of the pole through the existing locking mechanism.

For the initial installation tests at elevations of 20 to 30 feet (6 to 9 meters), an end support for the telescopic pole is not expected to be necessary, as the mount and static loop of wire would provide support throughout the extension of the pole. Once the AMD is secure to the trunk of the tree, the extended telescopic pole is manageable without end support. Future field tests are required to determine the height at which an end support is necessary for the safe retraction of the telescopic pole.

[1] Prices converted from British pounds on April 9, 2017.

The largest concern limiting the adoption of a telescopic pole for installations at heights greater than 30 feet (9 meters) is the rigidity of the pole. Promotional literature for the commercially available poles demonstrate a large amount of deflection in the pole that is predicted to hinder the installation procedure of "hanging" the AMD onto the trunk of the tree. The pole length limit will be determined through the field tests, setting the operation boundary between the telescopic and segment poles. At this point the implementation of the developed installation concepts can proceed to phase two. If the rigidity of the carbon fibre telescopic pole is found to not be a problem in the installation of the AMD, it is possible to procure commercial poles of 78 feet (23.8 meters) and custom poles up to 100 feet (30 meters) in length.

In addition to the purchase of a carbon fibre telescopic pole for phase one testing, it is also recommended that a direct tree trunk climbing aid be procured in the event that the retrieval of the AMD from the end of the pole is unsuccessful during testing. Preference is given to the Stepp Ladder presented in section 11.1.1 for AMD retrieval at heights up to 32 feet (9.7 meters). The addition of such a climbing aid for the testing phase removes the need for the setting of climbing ropes for the retrieval of an AMD at the low installation elevations for the current round of testing.

13.1.2 Phase 2: Segment Pole Installation

Upon the establishment of the operation limits of the hand operated telescopic extension pole and the efficacy of the static loop of wire for the attachment and retrieval of the AMD, focus can shift to the implementation of the pulley operated carbon fibre segment pole solution. The solution is recommended for the permanent installation of an AMD at the current installation heights of 60 to 70 feet (18 to 21 meters), with the potential for higher elevations.

Prior to the field deployment of the segment pole solution, detailed design and prototyping of the "rocker" tree mount, along with the associated pulley system, will be required. The results of the use environment field tests conducted with the hand operated telescopic pole in the previous phase will be instrumental in the further development of the "rocker" tree mount. The field tests of the "birdhouse wire" attachment and retrieval mechanism will guide the requirements of the mount to achieve the "hanging" of the device at the full installation height.

In contrast to the procurement of the carbon fibre telescopic pole from an established industry, it is recommended that the raw materials for the segment carbon fibre pole be obtained either from a direct supplier of carbon fibre segment tubes or as a custom order from a commercial manufacturer; versus the purchase and modification of a commercially available communication mast. The communication masts that were the inspiration for the use of a pulley operated segment carbon fibre pole are designed for payloads of 44 pounds (20 kg), far beyond the requirements of the 3 pound (1.4 kg) AMD. Therefore the components are far larger - and heavier - than is required for RFCx's purposes and are not suitable for direct modification. This is also reflected in the cost of the system versus the raw components. The 50 foot (15 meter), 2 mm outer diameter segment pole from Comrod is available for purchase at a price of $6,850 USD (Whitby, 2016). For comparison, similar raw carbon fibre pole segments for a 50 foot (15 meter) pole can be procured at a price of approximately $2000 USD, with a weight of 13 pounds (5.9 kg) (Carbon Fiber Tube Shop, 2016). Additional cost and weight savings can be achieved through the detailed design of the segment pole for the appropriate size required for the support of the AMD and mount.

13.1.3 Integration into Field Operations

Once fully implemented, the two concepts will integrate into the diagnostic testing and permanent installation activities of RFCx's field operations, described as the third and fourth stages of RFCx's operations in the field, in section 8.1.

For the diagnostic phase of field operations, an extension pole is utilized for the rapid deployment of multiple AMDs at low to mid range elevations (15 to 30 feet) for the collection of diagnostic data over the period of a couple of days. While this has been covered in detail with respect to the implementation of the hand operated telescopic pole, it is also possible to perform these temporary installations from a hand operated segment pole. Once a tree has been selected for permanent installation, the remainder of the AMDs are retrieved from the end of the extension pole.

The option for a second round of diagnostic data collection is available with the implementation of the tree mounted segment pole. It is possible to raise an AMD on the end of the pulley operated segment pole to be left erect overnight, to provide diagnostic data at the full installation height prior to the attachment of the AMD to the tree. This is made possible by the free standing nature of the communication masts that serve as the concept's reference. While the price of the segment pole makes this an uneconomical method of deploying a multitude of AMDs for general diagnostic data, it can provide additional data on select installation locations whose suitability are in question based on the initial diagnostics.

Upon completion of the diagnostics phase, the pulley operated segment pole system is deployed for the permanent installation of the AMD. Field operations are based on the process described in section 12.2.1.

13.2 Reflection

The results of the project are reflected upon in relation to the overall goals of the project, as conveyed through the mission statement and the interpreted customer needs. The limitations of the project are also discussed. As the true success of a developed concept is found in the reaction from the customer, their response is also included.

13.2.1 Meeting of Customer Needs

The final concepts were developed in an effort to meet the identified needs of the customer and the inherent requirement of an installation process that secures an AMD in a location where it is able to receive the necessary sunlight and cellular signal for continuous operation. While the meeting of the these inherent requirements has been described through the final concept's solutions to the subproblems of "raise", "attach", and "retreive" device, the concept's satisfaction of the remainder of the customer's needs will be discussed.

The carbon fibre extension pole and "birdhouse wire" method first and foremost addresses the expressed wish of the customer for the installation of an AMD to no longer necessitate the installer to climb the tree. The removal of the installer from the tree improves the safety of field operations by eliminating the risk of falls, thus lowering the potential liability experienced by RFCx. The general severity of a safety incident associated with the installation process has been lowered, as foreseeable incidents would involve the loss of control of the lightweight carbon fibre extension pole. The inclusion of top end and ground supports seek to lower and eliminate this risk.

The elimination of tree climbing greatly lowers the physical effort required by the operator to install an AMD. No longer is the operator required to lift their own body weight up the climbing rope to the installation elevation, but raise the 3 pound (1.4 kg) AMD and its mount on the end of a 7.4 to 13 pound (3.4 to 5.9 kg) carbon fibre pole. The implementation of the pulley system also serves to lower the physical effort required to raise the AMD assembly.

The elevation of the AMD on the end of an extension pole not only keeps the operator out of the tree, but also makes the installation process independent of the physical properties of the branches of the tree. Stated concerns with regard to tree branches centred on the situation where the nearest suitable branch for line setting is 200 feet (60 meters) from the ground. Additional difficulties were encountered with the size of the branches and the determination of their safety for climbing, with respect to rot or other damage. The removal of the use of tree branches in the installation process eliminates these concerns.

The properties of the carbon fibre extension poles address a number of the needs of the customer related to work in a remote rainforest. First, their light weight nature allow them to be transported through the jungle. Although the telescopic pole is far more compact than the segment pole, examples of backpack stored segment poles have been identified in section 11.1.2. The referenced weights of the telescopic (7.4 pounds) and segment (13 pounds) poles recommended in the previous section are under the 25 pounds per person requirement set at the start of the project based on the current gear carried in the field. Second, the durability and low maintenance associated with the extension poles make them suitable for extended field operations. The modular nature of both types of poles allow for the adaption and continued functionality of the poles in the case of damage, while the omission of lubricants, fuels, or other containments ensure that the installation method remains benign to the environment.

A stated hope of the customer was an increase in the number of trees available for AMD installation through the development of an improved installation process, with the problem related as only five in twenty trees identified as promising with respect to sunlight and cellular signal being suitable for climbing. The adaptability of the “birdhouse wire” attachment concept to a large range of tree trunk diameters, coupled with the elimination of tree climbing from the installation process and the independence of the installation method from the physical properties of the tree branches should greatly increase the number of trees available for installation.

A major ambition of the project was a reduction in the time required for the installation of an AMD, with a target installation time of 36 minutes. General time improvements have been achieved through the reduction in time required for tree identification as previously described, the capability to retrieve the AMD from the ground, and through direct improvements to the installation process. The elimination of setting a line as part of the installation process removes the largest time factor in the current installation method. While accurate time measurements will be collected from field trials, for reference the erection of the pulley operated communication masts require 20 to 30 minutes with two operators. This includes the time required to assemble the tripod base. Therefore the adoption of either carbon fibre extension pole should meet the installation time requirements of the project.

The capability to rapidly deploy numerous temporary AMDs for the generation of diagnostic data improves the efficiency of RFCx field operations. The reduction in the cost of time and effort required to place an AMD for temporary testing - through the removal of the need to climb a tree for both placement and retrieval - encourages the placement of a larger number of AMDs for diagnostic testing. The setting of the AMD from the end of a telescopic pole facilitates the placement of temporary installations at elevations closer to the permanent installation height to produce higher quality diagnostic data, to account for the discrepancy in cellular signal observed at different elevations. In instances where additional diagnostic data is deemed necessary prior to the determination of the suitability of a tree for installation, it is possible to gather data at the installation height from the end of the segment pole left erect overnight. This process was described in section 13.1.3. Improved diagnostic data, in terms of both quantity and quality, should result in an increase in the success rate in the selection of trees for permanent installation. An increase in this success rate would decrease the number of repeat operations required associated with the retrieval and re-installation of an AMD, regardless of the method of installation and retrieval employed. Improvements in the success rate of permanent installations are of all the greater importance while the permanent installation necessitates the physical climbing of the tree by the operator.

A key business goal of RFCx is the rapid expansion of their system. The need for a scaleable system was addressed in both the selection of the physical components of the installation system and in the simplicity of the installation steps. The main component of the installation method, the carbon fibre poles, are available for off the shelf purchases, as outlined in section 13.1. The remainder of the components, the "rocker" tree mount and AMD mount concepts, have been developed with a DIY skill level and attitude in mind. This is in keeping with the original spirit of RFCx's AMD. It is envisioned that the carbon fibre poles are to be shipped to partners in the field - or procured on their own - and the remainder of the components can be constructed locally. To facilitate the expansion of the RFCx's network of monitored rainforests, the installation method has been developed for operation by the secondary markets. The steps for installation are designed to be completed with a low level of operator skill and training. The stated philosophy of "less automate, more obvious" was followed.

Related to the need of a scaleable solution for the installation of the AMD, is the need for a sellable idea to be presented to partners and potential investors. For this reason, a simple to communicate concept was listed as one of the customer needs. While the sellability of the concept cannot be evaluated until it has been presented to a prospective partner, a key identified hurdle to the saleability of their current field operations - the physical climbing of trees - has been eliminated from the installation process. It will be left to the reader to judge if hanging the AMD in the tree from a long carbon fibre pole is a simple idea to communicate, as the author is bound to be bias in the analysis. The concept was put to the unscientific "Mom test" often put forth in the startup community, where the simplicity of an idea is judged by whether the founder's mother is able to understand the idea. The developed concepts passed (although this is again a biased result).

Also related to the perception of the developed concept is the latent need for a solution with "wow" factor to aid in the adoption of RFCx's system by partners in the field. The RolaTube mast described in section 11.1.2 was identified with the potential to meet this need, but was dismissed due to its high cost and weight compared to other extension poles.

13.2.2 Limitations

Limitations in the results are the cause of a number of factors. First, the use environment in which the developed product is to operate has not been experienced by the designer. Second, as the project was conducted by an individual versus a development team, it is probable that there are a number of biases inherent in the results. Third, as the outcome of the project was the development of a concept for the installation of an AMD, its true value will not be established until it has been tested in the field. The following section will look to address these limitations.

It is generally recommended in product development that the individuals who control the details of the project experience the use environment first hand, for it is held that without direct experience the technical trade-offs that must be made in any project may be made incorrectly and novel solutions to the customer's needs may be missed (Ulrich, 2003)[pg. 75]. With the geographical constraints of the project being conducted in Finland and RFCx' pilot projects located in South America, it was not possible for the designer of the project to experience the use environment first hand. Videos of field operations and pictures of the use environment supplied by RFCx were studied in lieu of first hand experience of the operational environment of a remote rainforest. The lack of first hand field experience necessitated the detailed description of field operations provided by Dave Grenell of RFCx, highlighted in section 8.1. Additional literature, videos, and pictures of typical rainforest environments were pursued to further bridge the gap in knowledge created from the lack of first hand experience.

Every project is bound to be influenced by the personal biases of those undertaking it. In a team setting, the individual members of the team can act as a counter balance to the bias of the other team members. In an individual setting, additional steps must be taken to ensure their biases do not negatively effect the outcome of the project. A number of steps common to all product development projects were taken to reduce the effect of personal bias on the final outcome of the project; including the use of neutral terms to describe both the problem and the solution throughout the project, the use of concept classification trees to identify gaps in the external and internal search for solutions, and personal reflection.

The use of neutral terms to describe both the problem and its solutions were adhered to throughout the project to avoid undue influence on the direction of the search for solutions. The form of the customer need statements presented in section 4.1 and 10.1 are an example of this use of neutral terminology, as the installation technique is simply referred to as the "solution". Neutral terms were also employed in the decomposition of the problem, as presented in section 10.2, with care taken to avoid the suggestion of a specific solution principle.

One of the stated benefits of the concept classification tree is the ability to identify the over and under emphasis in the search for solution concepts. Throughout the project, the classification trees would be reviewed along with personal reflection to determine areas of the search that were subject to neglect. An area of personal bias identified throughout the project was an aversion to the use of drones, the identification of which prompted a dedicated review of the topic to ensure that the field was not overlooked. Afterwards, the bias was justified by the customer through the desire for a simple solution.

As a concept piece, the performance of the concept can not be fully evaluated until it has been put into practice. While surprises are assure to arise upon the implementation of the concepts, a number of questions pertaining to the attachment, retrieval, and elevation methods of the concept are identified as areas of focus upon development of a working prototype. First and foremost, the performance of the "Bird house" wire static loop for attachment will need to be accessed in the operational environment, as the effects of potential growth on the tree trunks is unknown, as well as the surface friction of the tree bark. Second, the effects of time on the ability of an AMD to be retrieved possess a question, as it is theorized that creep and corrosion of the wire and plant growth may hinder the detachment of the static loop of wire from the tree. Finally, questions remain on the role of pole rigidity on the installation and retrieval process. It is currently assumed that flexibility in the carbon fibre poles, especially for the telescopic variety, will be a hindrance on the installation process. This will not be accurately determined until tests are conducted with carbon fibre poles. Also of concern with the use of extension poles is the performance of the "hanging" at the full elevation height, and the mechanical assistance that the operator may require. These questions with respect to the performance of the developed concepts will be answered through future field tests, with the concepts further evolving based on the observed results.

13.2.3 Customer's Response

Upon presentation of the results of the project, RFCx were specifically pleased with the simplicity and eloquence of the carbon fibre pole based solutions. The DIY nature of the components in particular struck a positive cord. Considerable interest was expressed in the commencement of field trials through future pilot projects, in particular in Ecuador, with test dates planned tentatively for 2017.

Part III

Summary

14 Conclusion

In product development, which concept development is the first step, it often cannot be known at the start of the project if a solution to the customer's needs will be discovered through incremental improvements to existing products and methods, or through the creation of a novel solution. For the task of the installation of Rainforest Connection's audio monitoring device - or Guardian phones - both results have been provided.

Incremental improvements to the existing installation method of manually climbing the target tree for installation of the AMD were presented at the end of the first phase of the project, in section 6. Recommendations include the implementation of the Rigger's Winch setup depicted in figure 5.21 on page 35 and the trial of a pneumatic launcher to aid in the setting of climbing lines. The Rigger's Winch setup eliminates the need for branch isolation, greatly reduces the physical effort required to ascend the tree to the installation point, and improves the safety of the climbing operation through the addition of the capability of lowering the climber from the ground by a second operator in the case of an incident. The addition of the pneumatic launcher for accurate line placement, coupled with the elimination of branch isolation improve the time required to set up the climbing system and thus the overall installation time for the AMD. The adoption of these improvements would not have a significant effect on the number of trees available for installation.

The novel solution of raising the AMD on a long carbon fibre extension pole, and "hanging" it onto the tree trunk from a static loop of wire provides a number of benefits to the installation process for RFCx, one of which is the increase in the number of trees available for installation. The method performs beneath the rainforest canopy on a wide range of tree trunk diameters and removes the need to climb trees for the installation and retrieval of an AMD, thereby opening up trees for installation that were deemed unsafe to climb. The elimination of tree climbing from the installation and retrieval process takes with it the safety concerns associated with the risk of falls and the negative perception on the ability to scale the system to protect the endangered rainforests of the world.

The process provides a quick, safe, and simple method for the installation and retrieval of RFCx's AMD in remote rainforests. The concepts are scalable through the combination of off the shelf products - the carbon fibre poles - and a do it yourself skill level for the construction of the custom components. The DIY approach to scalability is in alignment with the philosophy of Rainforest Connection and aids in the expansion of their system through partners in the field.

The project provides immediate value to the customer through the implementation of off the shelf telescopic carbon fibre poles for the rapid, temporary installation of AMDs at mid-range elevations for the generation of diagnostic data. The concepts initial deployment in this manner provides a natural path for the completion of field trails at a low cost of investment, while the improved diagnostic data - in terms of quantity and quality - aids RFCx in the selection of trees for the location of permanent installations.

Field tests conducted in this manner will provide valuable data for the detailed design of the pulley operated segment carbon fibre pole method, for the permanent installation of AMDs at elevations of 60 feet (18 meters) and greater. Questions remain to be answered in regards to the performance of the "hanging" attachment method at extended elevations; both in terms of the effect of the rigidity of the carbon fibre poles, and the suitability of the "hanging" motion from a fully extended pole. The field trials will answer these questions and indicate if the static loop concept will remain the best choice for permanent installations, or if an alternative - dynamic loop - concept will be required.

As part of the scope of the project, the developed concepts have neglected the precise placement of the AMD at the installation point in the tree, under the logic that future improvements to the AMD made by RFCx - and general improvements in technology - would decrease the importance of this step of the installation process. Once achieved, the pulley operated segment pole concept provides a promising path forward for the permanent installation of AMDs from the ground. Until that time, the concept provides RFCx with a scalable, sellable idea to present to interested third parties.

At the conclusion of the concept development project, Rainforest Connection are provided with a an immediate tool to enhance the efficiency of their field operations and a development path to allow for the permanent installation of their audio monitoring devices from the ground. The implementation of the hand pushed telescopic pole for the rapid temporary installation (and subsequent retrieval) of AMDs will provide immediate field test results for the continued development of permanent installation technique and improve the selection of permanent installation locations through enhanced diagnostic data. Until a time when improvements to the AMD decrease the role of in tree placement in the installation process, the incremental improvements provided for the current tree climbing process further improve the efficiency of RFCx's operations in the field.

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Appendix 1

Expert Communications

Appendix 1.1 2015-11-24: Email - Sean Cogan of Harken

Harken PowerSeat

Participants: sean.cogan@harken.com, gpaddick@gmail.com

Sean Cogan

19 November 2015 at 17:16

Hi Gary,

Thanks for the interest.

The PWRS-G (Gas model) retails at $7040 The PWRS-B (Battery Version) retails at $8300

The battery is 48v that charges on any 110v outlet. The Electric platform is the same as the full electric PowerSeat (PWRS-E), so the battery offers the system to be convertible between a transformer (corded) power supply or the battery as the power supply to the motor. The PWRS-E retails a bit higher (11k), which is mostly due to the transformer, so I suggest saving some dollars with the battery and you can purchase extra batteries vs the transformer. Unless you intend to use the PWRS as a fixed point anchored winching system, I find the cord does get in the way at times.

What is your intended use? What type of work are you performing with the seat? (we can work with you a bit on price) Thanks Gary, Sean

Sean Cogan New Business Developement Manager N15W24983 Bluemound Rd. Pewaukee, WI 53072 sean.cogan@harken.com p: (828) 577-1651

Gary Paddick

19 November 2015 at 17:56

Thanks Sean,

Very much appreciate the quick response.

I'm looking to see if it would be a suitable option for some work we're doing in the Amazon and other rain forests. I'm working with a young NGO that places audio devices up in the trees, below the canopy, to provide real time monitoring. I'm looking into methods to improve upon their installation method, and right now one of the largest complaints is the time and effort required for ascending the tree/rope. Which is how I came to find out about Harken power seats.

Typically heights between 60-70 ft (18-21 m), although they can reach heights of 120 ft (36 m). They're also having the issue with the rope placement and location selection, which has the end result of them having to do multiple climbs per installation.

Thanks for your help, Gary

Sean Cogan

19 November 2015 at 18:04

Understood. Sounds like some good work to be in on.

The PS would give the option of either riding the ascender or anchoring at the base of the tree with a line going up to a redirect pulley and back down to a climber. This way someone can press a button and haul the climber and needed gear up, but frees the climber of any extra weight to deal with in the canopy. Another option that could accomplish this at a much less cost would be our RW500, that can be driven with a drill for a similar affect.

IF you ever need an alternate, I'd jump at that opportunity! I spent a fair amount of time working the canopies of Belize building zip tours and now as a SPRAT L3 mainly doing bridge inspections, I miss the tree work at times…

http://www.harkenindustrial.com/product/riggers-winch/

Happy to help any way we can. Sean

Gary Paddick

19 November 2015 at 18:23

Thanks Sean, the RW sound like an interesting option. To be honest I'm a little new to this area of work. How would you go about installing the redirect pulley? Ideally they would only like to perform a single climb.

What do you think the rough cost of a system utilizing the RW cost? How powerful a drill are we talking? Have you ever utilized such a system in Belize?

Thanks!

Sean Cogan

20 November 2015 at 16:51

Hi Gary, I'm in between travel briefly. I will follow up with you when I get back to the office tonight, or first thing Monday... Apologies for the delay Sean

Sent from my iPhone

Gary

20 November 2015 at 17:17

No worries Sean, sounds good to me!

Have a good weekend.

Gary

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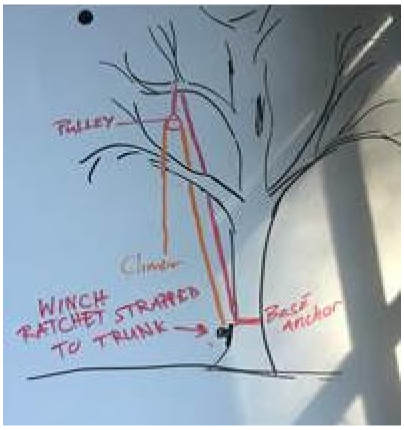
24 November 2015 at 19:20

Hi Gary, Again, my apologies for the delay.



Pardon my sketching skills, but this is how you could rig the tree for lifting with a smaller winch. If where they are setting the monitoring equipment is close to the point of access, then the PowerSeat is hard to beat. Just trying to give you an idea for options.

We were not fortunate enough to have this kind of stuff available to us in Belize… would have made a world of difference in tensioning those cables!

Let me know how I can help. Sean

Appendix 1.2 2016-01-21: E-mail - Donald Hill of Reach It Add-A-Pole

Subject: Add a pole Participants: gpaddick@gmail.com, reachit1@verizon.net

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Gary

21 January 2016 at 19:41

Hello,

I came across your interesting product while hunting online for the longest extended pole I could find. I was curious about some of the specs. How heavy is each pole section (so not including a saw head) and how high/long have you managed to extend the pole and still maintain stability?

I'm interested in utilizing it for the installation of a camera trap like device as high up as possible into trees. The camera trap is around 3 lbs, but I have thoughts on reducing the weight required for the pole to support.

Cheers and thanks, Gary

Donald Hill

21 January 2016 at 20:05

Gary , Each 6ft pole weighs 2 pounds and u can add 8 poles with the 3 pound camera reaching 50 ft easily!! And stable !! 8 —6ft poles total $300. Plus shipping . Thank you, Don

Sent from my iPhone

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21 January 2016 at 20:54

Awesome, great news! Thanks Dan.

I'm going to do a bit more work on how exactly to attach the camera trap off a pole, but knowing that the poles can remain stable at the height is a great sign. Out of curiosity, how heavy is the 1.5 HP saw that is normally attached or some of the other attachments? The poles are 1.75" diameter correct?

I believe on one of your sites one product mentions "OATSS-PSPHDA 6FT POLE SAW POLE HEAVY DUTY ALUMINUM HIGH REACH 40 TO 60 FT" Are there any specific specs on this, or is it 6 - 10 poles?

Have you used these poles at these heights often.

Thanks again, Gary

Donald Hill

21 January 2016 at 21:35

Gary – yes – u want to purchase the heavy duty poles for stability – the saw is 6 pounds— and u will lose stability above 50 ft but u can in some cases control it with leaning the poles on limbs etc at different intervals. We have been doing tree service using the saw system since 1998 and have worked at various heights and u will lose control at extended heights above 50 ft Don Sent from my iPhone

---

Donald Hill

21 January 2016 at 21:35

Poles are 1-3/4” dis

Appendix 1.3 2015-11-26: E-mail - Daniel Holliday of ClimbingArborist.com

Subject: Thanks for the great site and a question on long ascents Participants: gpaddick@gmail.com, mail@climbingarborist.com

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Gary Paddick

26 November 2015 at 10:11

Hello there!

Just wanted to send a thanks for the great site. Really useful info and clear explanation. I've been looking up different climbing systems and at times it felt like I was hitting my head against the wall with all the different techniques and gear. You really cleared a lot of it up!

Had a quick question if you don't mind. I'm working on a rain forest conservation project as a master's thesis and the guys that are climbing the trees are having a real hard time getting up in the tree. Seems line setting and the physical effort, along with bugs (ants) are the biggest concerns (along with safety)

Was wondering what in your opinion is the more efficient ascent technique for long distances? Talking at least 60 - 70 ft, and in some cases 120 ft. Would a secure foot lock method with a false crotch be easiest for ascent, or a pure SRT system with a frog walker system be easier?

Thanks again for the great site, and no worries if no time to answer the question.

Cheers, Gary

Dan Holliday

26 November 2015 at 12:36

Hi Gary,

Thanks for your email. It's always really nice to hear from people that are using the site and finding it helpful.

To answer your question, definitely using an SRT system is going to be the easiest way to ascend. Footlocking takes a lot of practice and technique to get right and it still requires much more energy. A good SRT system is very efficient once you have practiced with it a few ties and you can easily rest whenever needed.

Which rainforest are you doing your project on?

Dan Holliday

Gary Paddick

26 November 2015 at 12:51

Thanks Dan!

Their next pilot project is in Ecuador (I'm based remotely in Finland). They've been working so far in the Brazilian Amazon, Central Africa, and Indonesia. They're installing audio monitoring devices in the trees just below the canopy.

One other question. What would your time estimate be for a climb of 60-70 ft or 120 ft? They're telling me it's taking them in some cases more than 1.5 hrs, which seems a little extreme to me, but since I haven't yet had a chance to tree climb, it's hard for me to go on much more than there word.

It's one of the reasons they're looking for a way to avoid climbing the trees and install the device remotely, which seems way more complicated then just climbing up.

Thanks again, Gary

Dan Holliday

26 November 2015 at 13:00

Gary,

It depends when they say 1.5hrs, if this is purely the time taken from them leaving the ground until reaching the top. What I imagine they mean is the time it takes to set the rope in the tree, then prepare their equipment and then ascend. If this is the case that isn't an unreasonable time depending on the size of the trees,the branch structure and ease of getting their access line in.

Are the climbers drafted in specifically for the project? Are they specialist tree climbers? Where are they based/from (e.g. South America, U.S)

Dan Holliday

Gary Paddick

26 November 2015 at 13:12

Thanks for the insight Dan.

That's quite possibly the case, although they have made it seem like the actual ascent time. I'm pretty sure if that was the total installation time they would be pretty happy. They have mentioned difficulty in using the big shot and getting lines close enough to the tree trunk for installation. They've especially mentioned having spent the effort to climb up, only to find out they're not in a good position to install once up in the tree. I'm hoping to get a better picture of the full situation this week. (Your site has certainly better prepared me to understand what they're doing).

I've asked the method they're using, and they weren't able to say at the time, but directed me to the site of the people they learned from. Also that they're using a jumar and foot ascender. Based on the site it looks like they're using a Double rope method. They sent me one video and it looks like something similar to a sit-stand method.

As to the climbers themselves, it's the founders of the NGO. They're based out of San Francisco. Definitely not specialized tree climbers, though at least one them seems to have some rock climbing experience.

Dan Holliday

26 November 2015 at 13:26

The ascent itself with someone trained in using SRT systems should take between 3-10mins. If they are using Jumars (hand ascenders) and a footloop this is an older form of SRT but no way near as efficient as the frog walker system.

I'm to sure how big this project is, but if they need help/training at any point, I would be more than happy to go with them if they where to cover the cost of the flights.

Do you have any videos/links of them working on this project?

Gary Paddick

26 November 2015 at 13:43

You're most likely right on the SRT. I took a closer look at the video, but it's still hard to tell. Not enough resolution for my eye.

Here's the only climbing video I have:

https://www.youtube.com/watch?v=YEBKN1SvnRc

I'm not sure on their budget, but I'll be sure to pass along the offer and see what they say!

Gary Paddick

26 November 2015 at 13:43

Your based out of Canada now, correct? BC?

Dan Holliday

26 November 2015 at 14:03

Yeah from the video that does look like an older system, and looks like really hard work. I am actually going out climbing today so I will get a short clip of how easy it could be for them with the right equipment.

Yes, I live in Vancouver, B.C, Canada.

3mins would be someone like myself who has lots of experience with tree climbing. 10mins would be someone with the right equipment and training and is relatively fit, but without all the experience.

I just looked up the project, I remember reading about this a while ago, it's a really good initiative, please pass on my information, I would very much like to be a part of it.

Dan Holliday

Appendix 1.4 2016-01-28: E-mail - Perry Tait of Reach IT

Subject: Custom Carbon Fibre Telescopic Poles Participants: gpaddick@gmail.com, perry@futureofcleaning.com

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Gary Paddick

28 January 2016 at 11:34

Hello,

Well looking up water feed poles and carbon fiber poles I came across your video advertising that you not only make water feed poles, but also custom carbon fiber telescopic poles. I've looked through some more of your videos and website, and I'm excited by the possibilities.

I'm working on a project that installs audio monitoring devices in trees in the rain forest. The range needed for installation and the desire for a ground installation method is what have lead me to look at carbon fiber polls.

The installation heights range from 10 ft installations for testing to 60 ft permanent installs. If possible the higher the better for the permanent installs, with some installs taking place at 100 ft.

The required sets of ranges is one of the reasons why I can see some similarities to the WFP.

One of my biggest questions/concerns is the weight that a pole can support at different lengths/heights. I noticed in your youtube video that you made the pole for a photographer to hold 2.5 kg. Would it be possible for you to provide some specifications on the poles regarding the end payload a pole can support?

The device I'm looking to install is around 1.4 kg (3 lbs), plus an installation mechanism (I'm envisioning something similar to yard-work poles with a pull string mechanism, similar to shears), but the mechanism type will be dependent on the weight a pole could support.

The intention for the high elevation (60 - 75 ft) installs would be to support the pole against the tree trunk while raising it. For the low level installs (10 ft) it would be preferred if the pole was rigid enough to remain rigid without the support of the tree.

Thanks for your time and looking forward to hearing from you.

Cheers, Gary

Perry Tait

29 January 2016 at 06:23

Hi Gary

This is a pretty typical enquiry for us .. the FLORA and FAUNA industry use a lot of telescopic poles . . .

We can certainly make the poles you need .. what a great project !

With 1.5kg, you have no problems .. we have tested 5kg to 50ft for the Israeli Army - they use our poles to raise rope ladders up to 5 storey window sills in hostage events ..

Carbonfiber will not break from use - you cannot over-stress it - only if you drop it can it break from an impact on a sharp edge.

We have 3 different modulus of carbonfiber that have varying rigidity, and price . . . so its a case of how accurate you want the pole to be at full extension.

Give me more info, and I will steer you in the right direction ..

If you wanted to test, grab a Reach-iT PRO - I can discount that to USD$1200 so you can experience High Modulus Carbonfibre . . . It is 40ft . If you want to go to 60ft, you can use PLUS A,B and C - see Catalog attached . . .

Regards

Perry

Appendix 1.5 2016-06-13: E-mail - Tom Whitby of COMROD INC

FW: Info on ULM-C 48/15-1.3 Participants: twhitby@comrod.com, gpaddick@gmail.com

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Tom Whitby

13 June 2016 at 23:26

Gary, Good afternoon. Thank you for contacting Comrod. The ULM-C 48/15-1.3 mast can be sold to civilians. They mast kit would cost $6,850 (FOB Cleveland). The mast kit contains (15) 1m long carbon fiber sections each weighing 2 lbs. The entire mast kit weighs just under 100 lbs and comes transportable in two bags.

I hope that answers your questions. Please let me know how I can be of further assistance to you. Thanks and have a great day.

Tom Whitby, PE COMROD INC Director, Business Development Mast Systems

12830 Triskett Road Cleveland, Ohio 44111 Ofc: (216) 252-6610 Cell: (216) 870-9746 Email: twhitby@comrodusa.com www.comrod.com

Appendix 2

Concept Classification Trees

Appendix 2.1 SAO Concept Classification Trees - Phase 1

The full version of the the concept classification tree created throughout the state of the art external search conducted in phase 1 of the project is provided. Plus signs indicate areas of the classification tree available for further expansion. These sections have remained collapsed due to page constraints. Figure 2.2 is the drilled down view of the collapsed branch in figure 2.1.

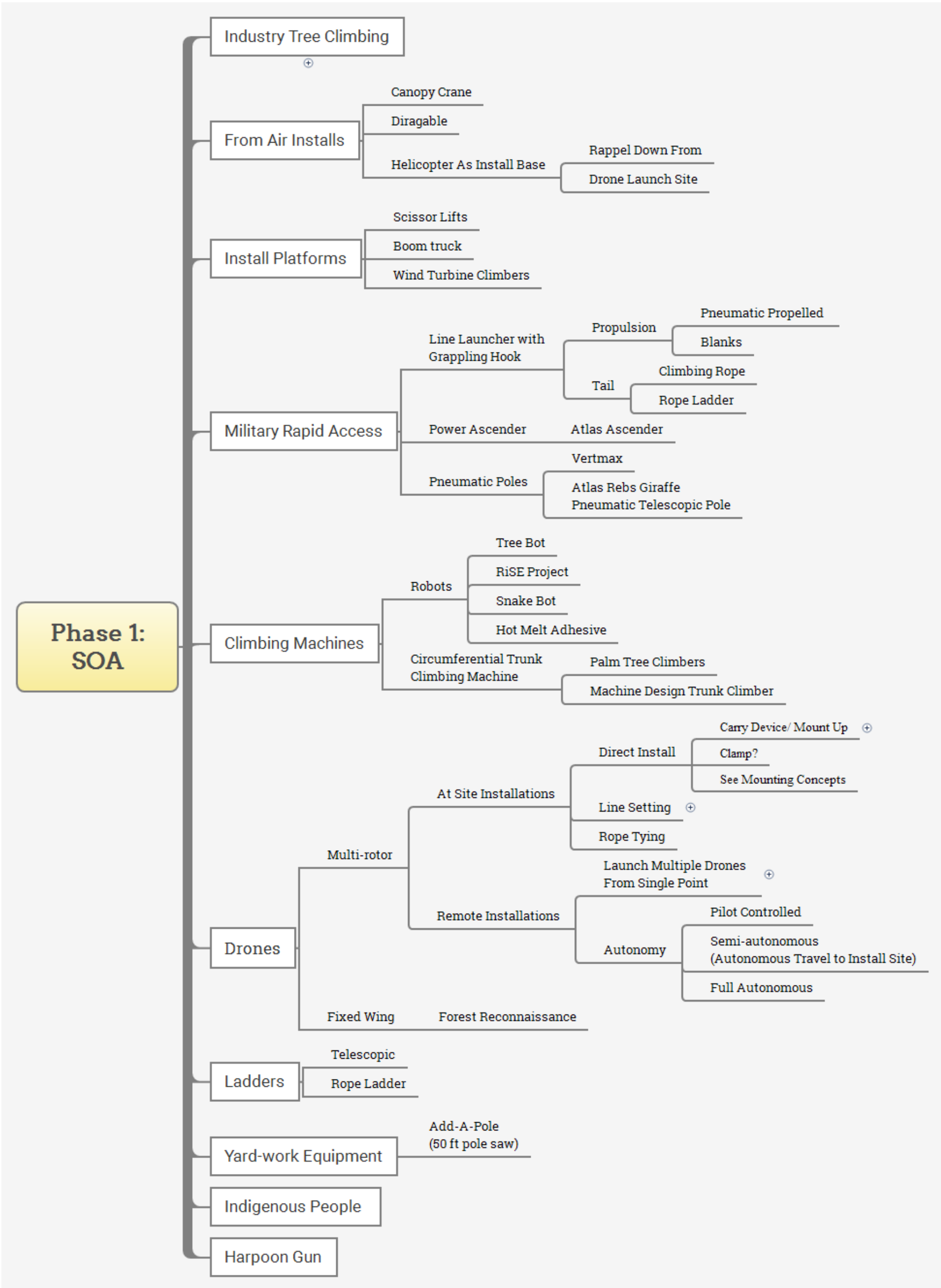

Figure 2.1: Concept classification tree - SOA (with industry tree climbing branch collapsed)

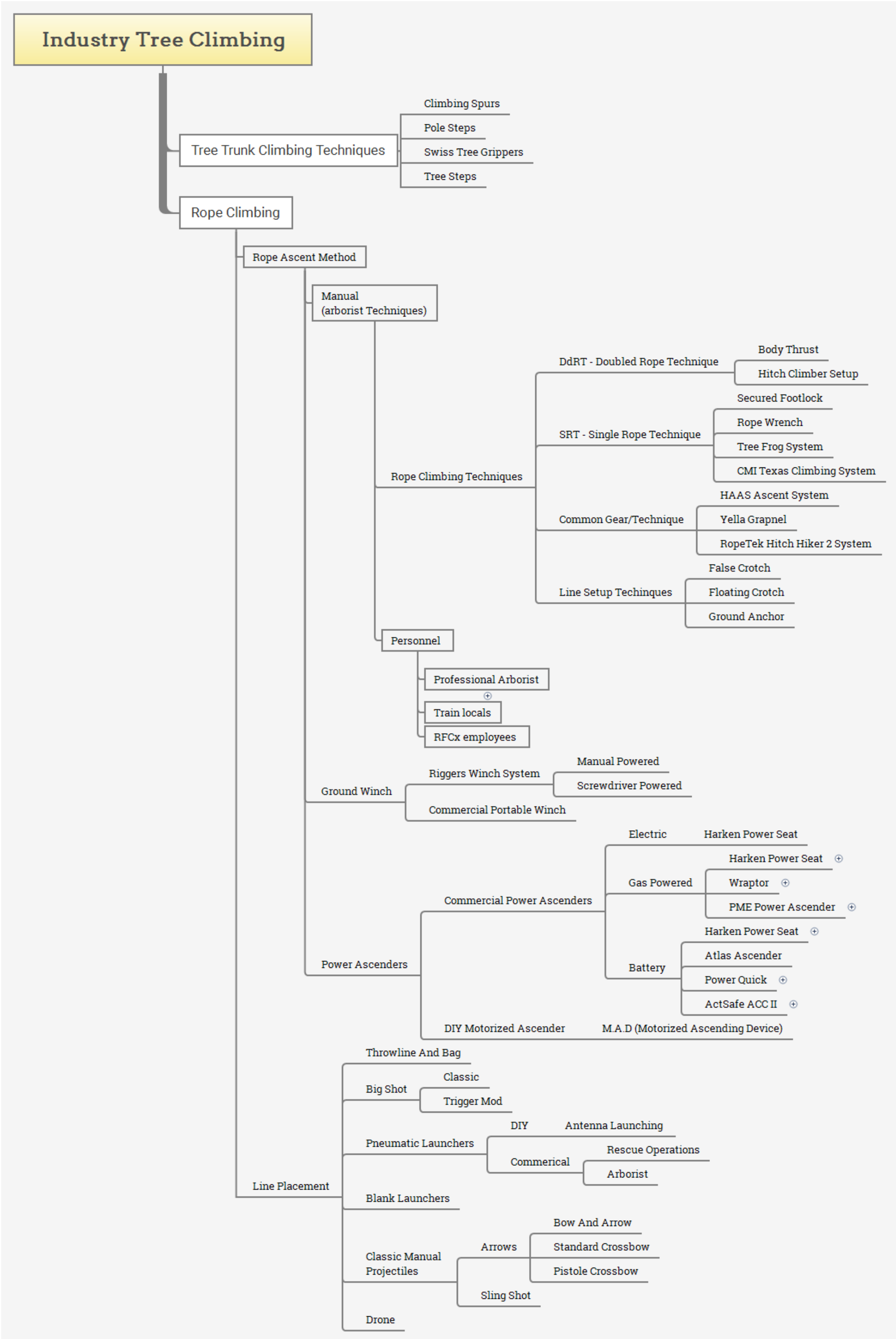

Figure 2.2: Concept classification tree - SOA (industry tree climbing expanded)

Appendix 2.2 Concept “Generation” Tree - Phase 2

The concept classification trees created as part of the internal and external search to guide concept generation are divided by the subproblems of “Raise”, “Attach”, and “Retrieve” device.

2.2.1 Concept Classification Tree - Raise AMD

The concept classification trees for the subproblem of “Raise” device. The overall concept classification tree is presented in figure 2.3. The “Personal Climbing Techniques” branch is collapsed in figure 2.3 and presented in figure 2.4. Expanded detail of the “Long Pole” branch is presented in figure 2.5, with the “Long Pole Support” branches further expanded in figure 2.6.

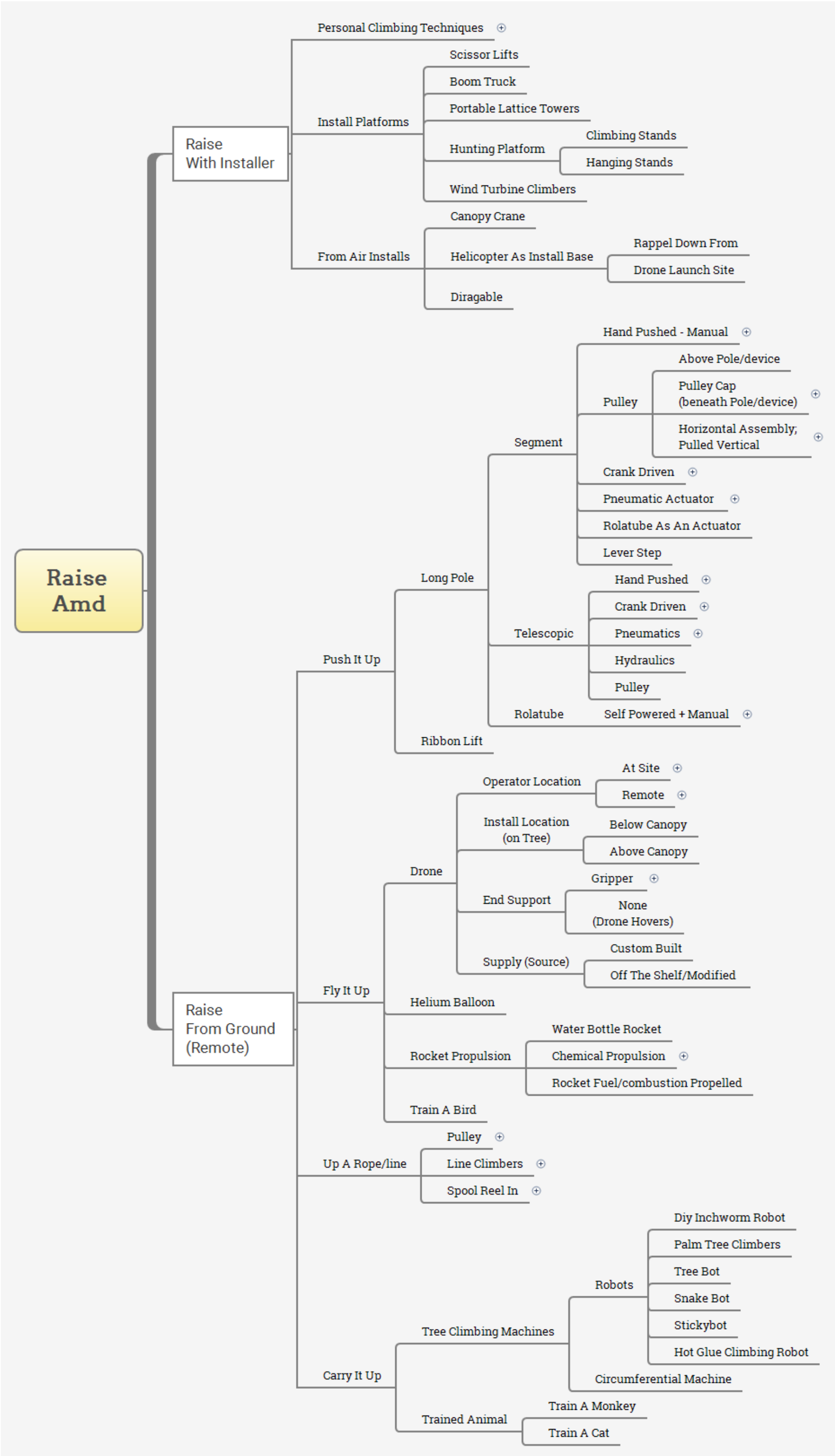

Figure 2.3: Concept classification tree - Raise AMD ("Personal Climbing Techniques" collapsed)

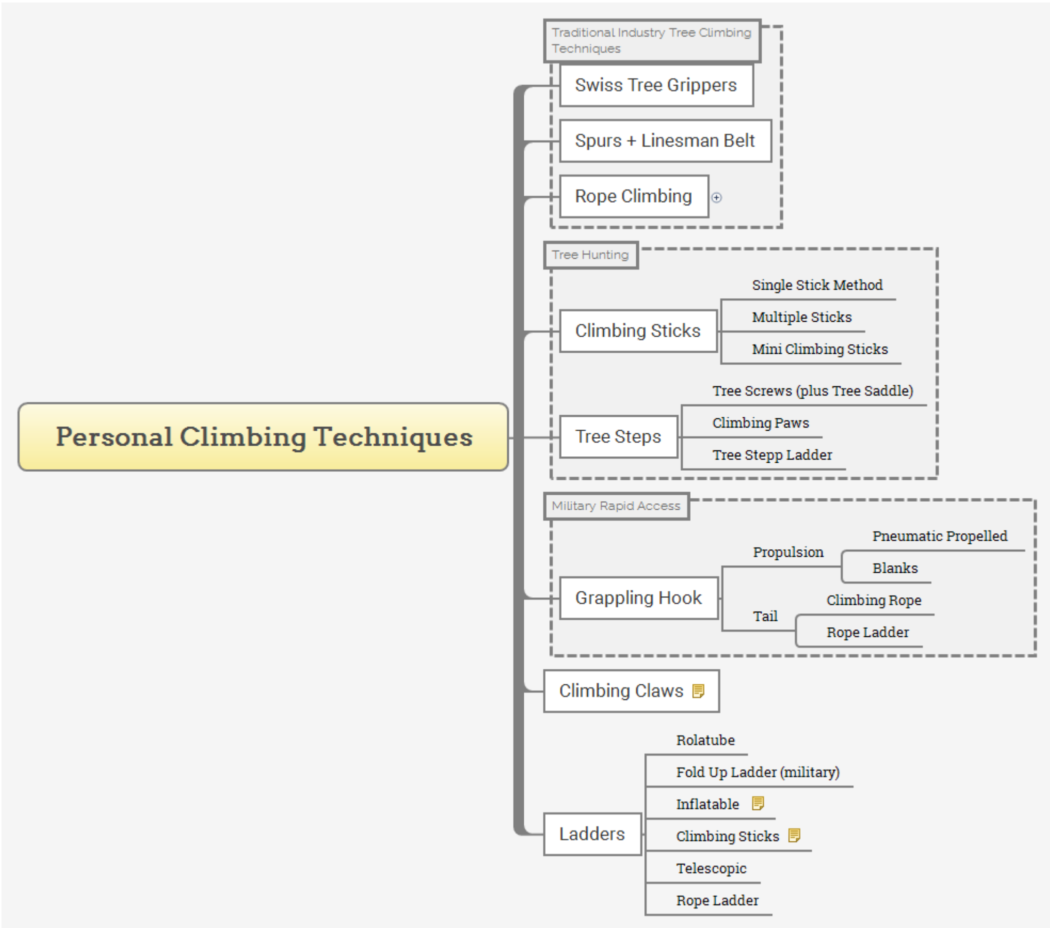

Figure 2.4: Concept classification tree - Raise AMD ("Personal Climbing Techniques" expanded)

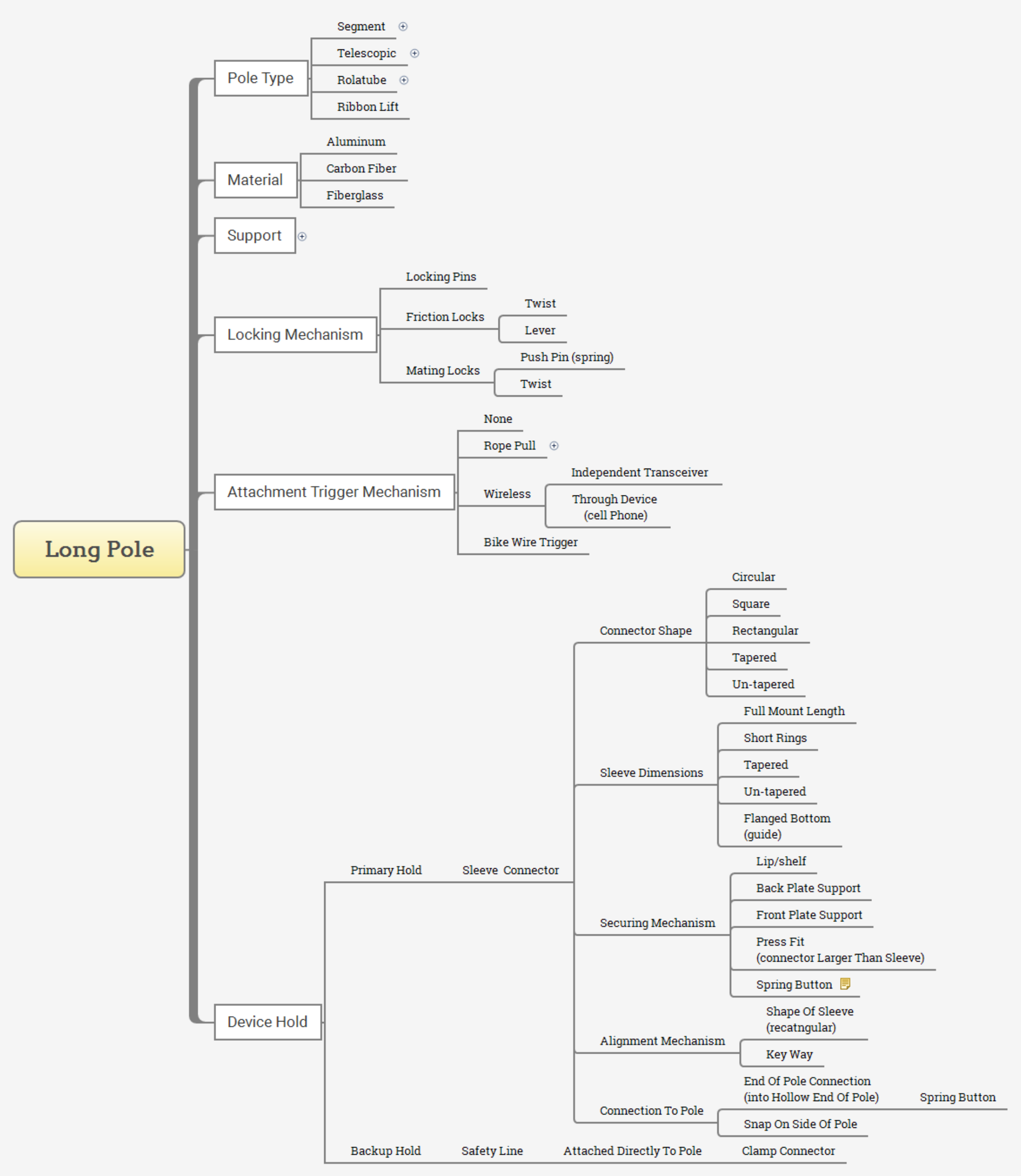

Figure 2.5: Concept classification tree - “Long Pole” expanded detail

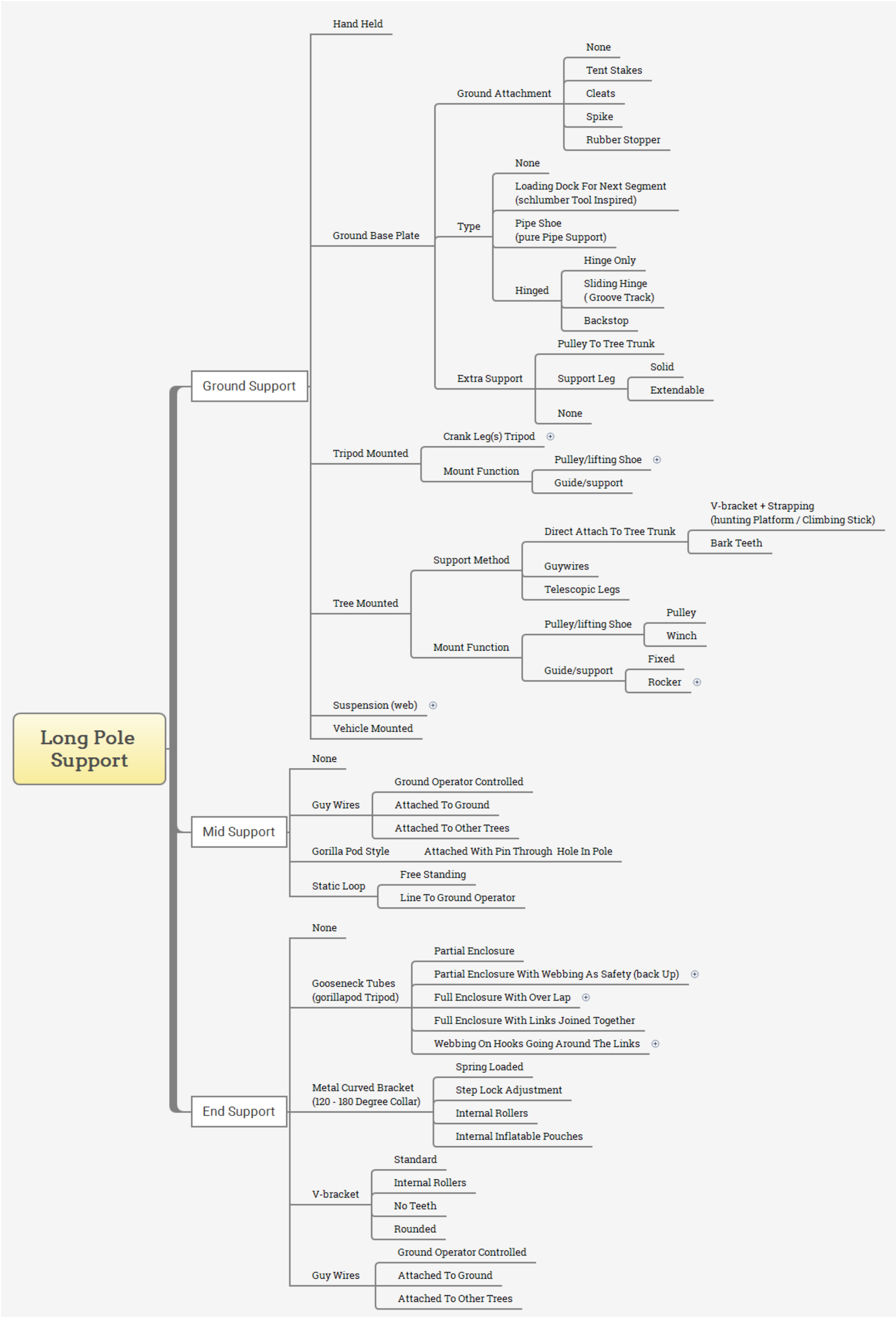

Figure 2.6: Concept classification tree - "Long Pole Support" expanded detail

2.2.2 Concept Classification Tree - Attach AMD

The concept classification trees for the subproblem of “Attach” device. The overall concept classification tree is presented in figure 2.7. The “Loop of Material” branch is collapsed in figure 2.7 and presented in figure 2.8. Additional detail on the AMD mount is presented in figure 2.9.

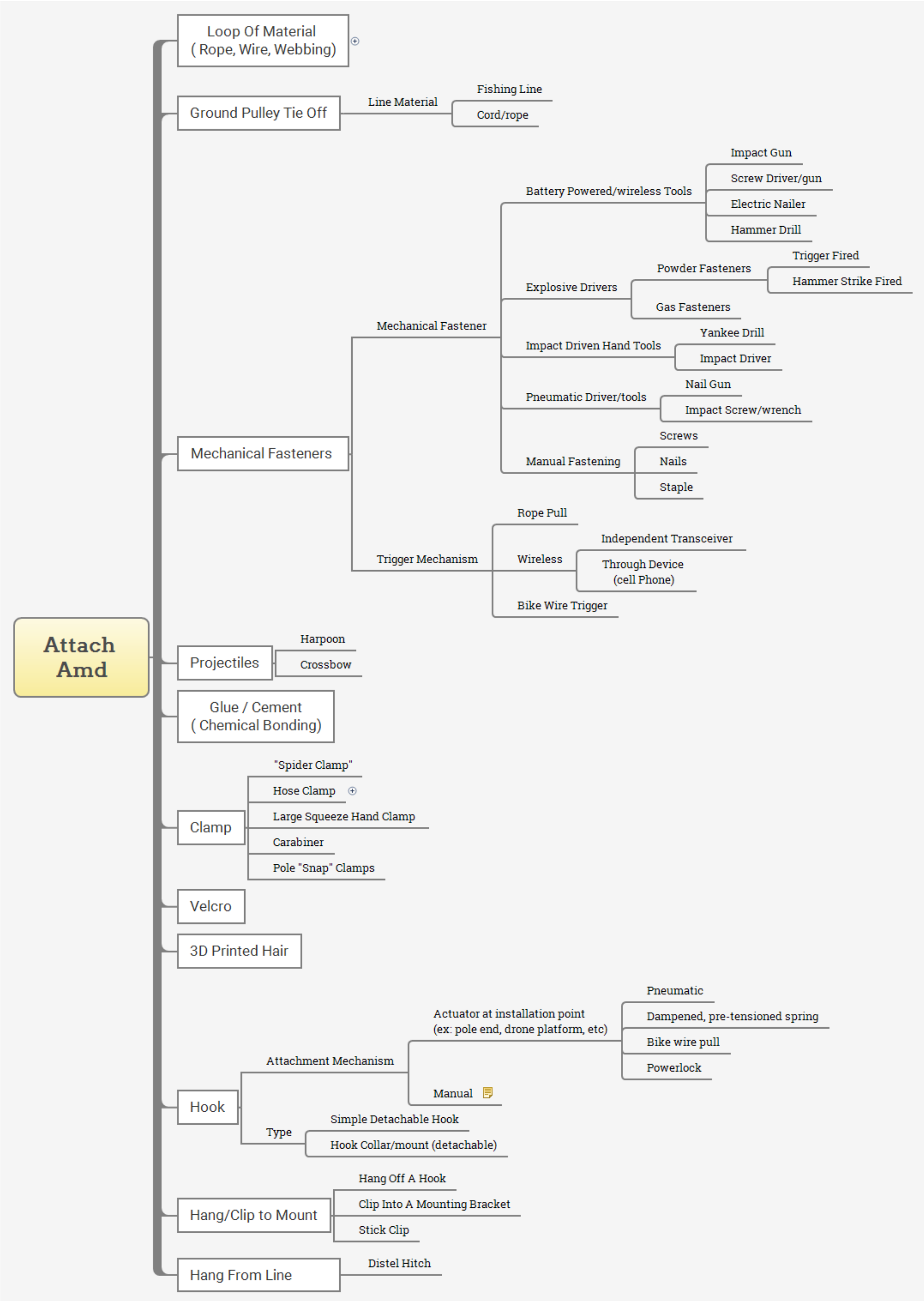

Figure 2.7: Concept classification tree - “Attach AMD” (“Loop of Material” collapsed)

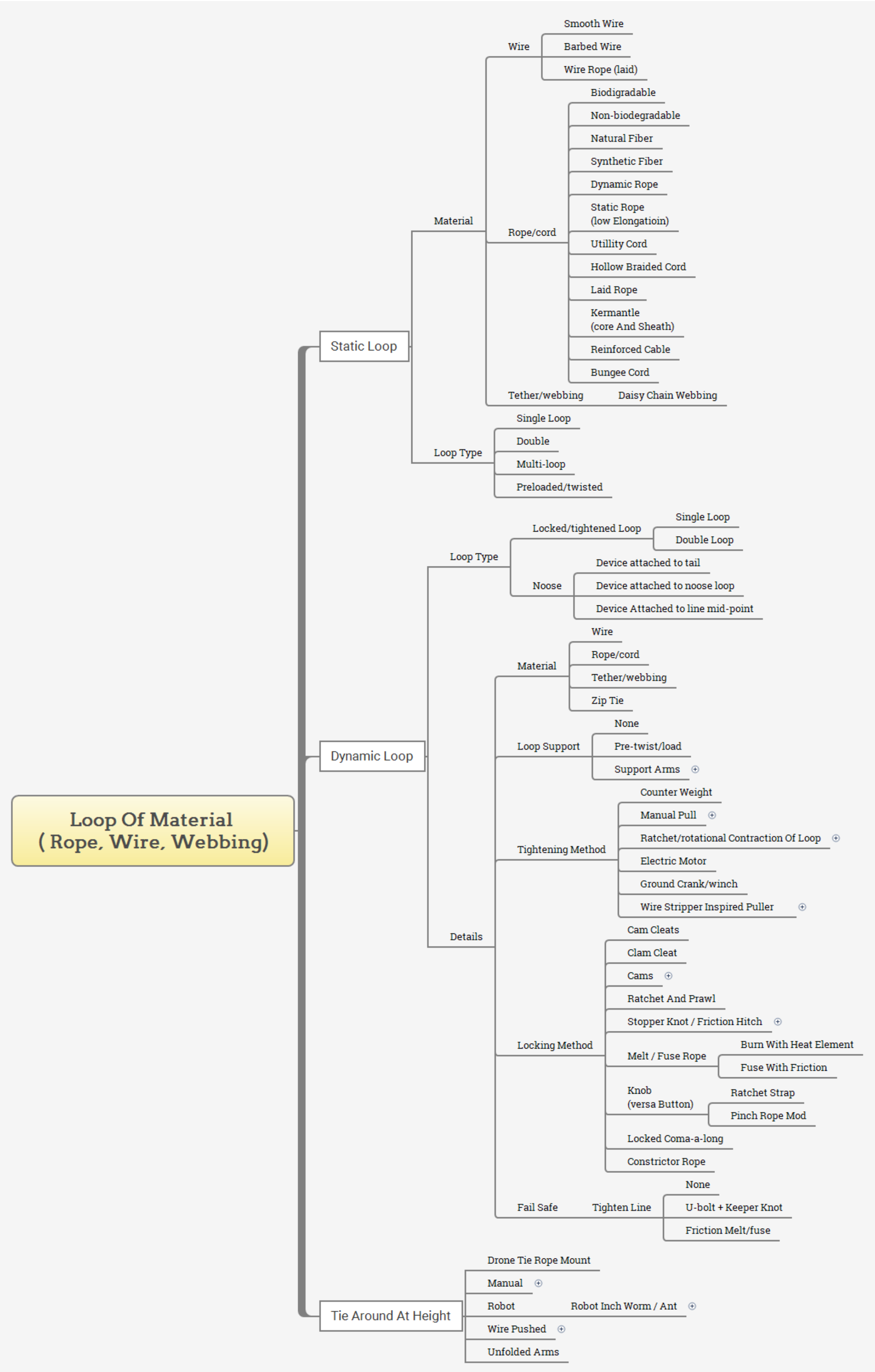

Figure 2.8: Concept classification tree - “Loop of Material” expanded detail

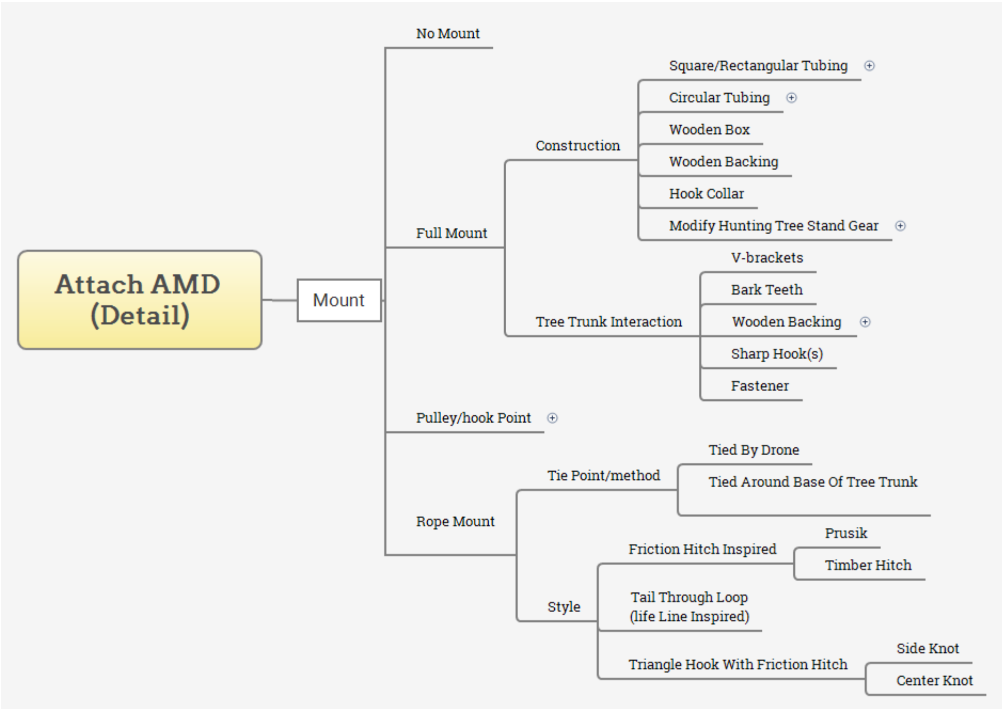

Figure 2.9: Concept classification tree - “Mount” expanded detail

2.2.3 Concept Classification Tree - Retrieve AMD

The concept classification trees for the subproblem of “Retrieve” device.

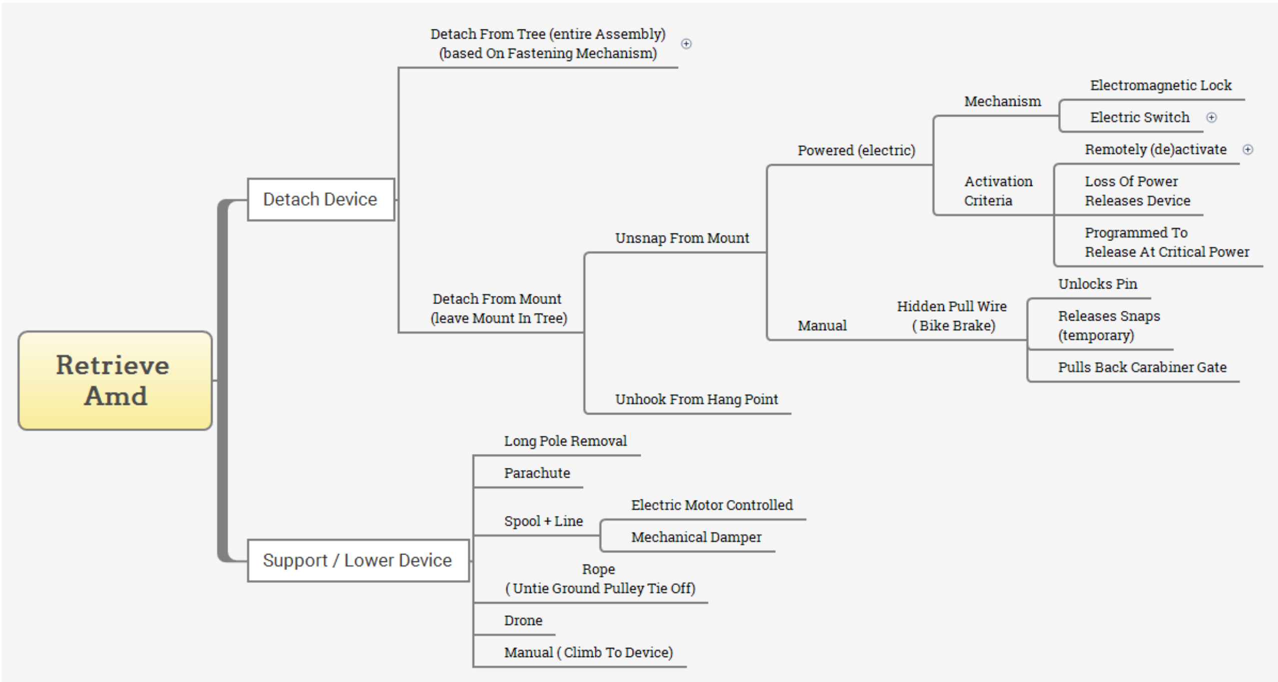

Figure 2.10: Concept classification tree - “Retrieve AMD”

Appendix 3

Customer Interviews

Appendix 3.1: 2015-12-14: Field Operations in Cameroon with Dave Grenell

Interview with Dave Grenell from RFCX

December 12, 2015

Interview Participants:

- Dave Grenell (RFCX)
- Gary Paddick (Aalto)

Interview duration: 1:18:42

Interview medium: Skype with audio recording.

Note: Much of the information comes from first hand field experience in Cameroon.

0:00 -2:00 Greetings exchanged

Dave Grenell:

- I was a rock climber for many years in college. Never got around to ice climbing. …

Gary Paddick - Explanation of Process – (2:00)

- I want go step by step from when you step off the plane to when you step back on the plane. Want to get the full picture.

Dave Grenell:

- Cool, you should stop me and direct the conversation anytime, so that I don't end up just talking. Make sure it's useful for you.
- Since every location is a little bit different instead of generalizing, which we can do, I'll start with Africa, as an example.

Dave Grenell: (2:40)

- We apply for a grant.
- We get a grant.
- Get our plane tickets and visas together.
- We bring all the equipment with us. Normally two duffel bags. One would be climbing gear, the other would be devices.
- We arrive in Cameroon, hopefully the bags don't get delayed for extra inspection, because that's weird. Stuff that's inside.
- Cameroon we didn't get our bags until a couple of days after arrival.
- Then we drive 7 hours into the interior into a really remote rainforest.
- That particular case there's some sustainable logging going on.
- We're going to work with the zoological society of London to run test on whether the system would work there.

- They identify places with cell service.
- They've already given us a map, before we've arrived.
- **When we get there, the first thing we do is test the areas that they've identified for cell service. To see if that's real.**
- The way we do that can be as simple as taking one of the refurbished phones that we use and walking around in that area and seeing how many bars, or actually taking very careful measurements in some cases.
- Then we'll cross off the list, the locations – by going to each of those locations – which of those have the best cell service.
- Now that can take weeks.
- If they have a lot of locations

Gary Paddick: (4:30)

- How are you normally traveling? Are you guys on foot, truck, or dirt bike?

Dave Grenell:

- We're always in a car.
- Then we drive to the location and then we start walking.
- Always vehicle/on foot.

Gary Paddick:

- How far away from the vehicle are you walking on foot?

Dave Grenell:

- For the first tier of installations we would always look at key access points near roads
- So not far.
- The area of cell service, let's say they've identified an area of cell service and there's a road there, our first choice would be to put up devices in that area, near or on that road.
- That's useful for diagnostics and testing. You can get immediate data on vehicle traffic.
- So you can do a lot of measurements based on those early installations.
- Then you can move deeper into the forest once you know that area is working pretty good.
- Arriving at a particular location I would say assume 1 hr to drive there. Might be 40 mins.
- Get out, spend; running the diagnostics and crossing them off the list, that might take an hour, and once you come back to do an installation, first I would go back… that's one trip.

Dave Grenell: (6:15)

- Then the next trip, <u>you go back and look at locations to put up a device</u>. I would say that could be 3 to 4 hours.

Gary Paddick

- **That's not 3-4 hours of walking though?**

Dave Grenell:

- **Yeah it is.**
- That's 3-4 hours of trying to move through impenetrable jungle, and locating trees.
- That can take you 20 mins to go 100 yards (91 m), unfortunately, sometimes.
- You look at one tree, you kind of pick spots looking at some of the things you specked out; like tree cover, sunlight, you look at the road in terms of is the road flat, is the road on a hill.
- There are different features that would have acoustic ramifications in terms of catching sound.
- I would make a list of locations, like trees that look really promising and if I had the time I would probably take measurements in those locations.
- The way we will probably do that soon is try to not be on the ground to take the measurements, because the difference can be large, if you're on the ground versus a 100 feet up.
- Think going forward have the hexcopter, but the phone in the hexcopter, float it up, 50 – 100 ft. and actually record the measurements at that level.
- Then come down and be "Oh, that's a good reading! That's a tree worth going up."
- I would try and find 5 or 6 candidates for trees.
- Things you're looking at, would be any standard arborist training.
    - Is the approach easy? When you get to the tree you walk around the tree 360 degrees.
    - You look for ailments on the tree, possible deadfall from dying branches above.
    - You look for insects, beehives.
    - Look into the canopy, are you going to be able to shoot a line. What limb are you going to go over?
    - All those things.
- And I probably wouldn't take any notes on that, 'cause that's just kind of a mental reference.
- I wouldn't. I know Topher wouldn't.

Dave Grenell: (8:37)

- Then I would pick my top 3 (trees) and I would go back a **3rd time** to do an installation.
- I would probably start with 1 to 2 trees
- Now if you had a mile of road, like in Cameroon, in Africa. This one road was the most important thing to monitor.
- It's like a road that protects 1000s of km.
- If you can monitor the road you can really see what's going on there and stop stuff.
- In that case I would put 1 device every 300 or 400 yards (275 – 366 m) down the road, and maybe on opposing sides of the road. One on this side, another on this side, and kind of stagger them.

- In the best of all possible worlds, we would low mount them for testing, if we were getting really good cell service.
- So I wouldn't go up the tree. I would just stick it on the tree, but wouldn't go up the tree.
- That didn't really work so good in that case.
- If you could low mount them, what we did was that (low mounting).
- Then we go back to the base and taking measurements and readings
- It's like, "Ok the diagnostics aren't that great," so we would need to go back and go higher up the tree.

Dave Grenell: (10:10)

- That's the full thing in terms of we're taking our gear, in a backpack.
- Someone is usually dropping us off if we're going to be 4 or 5 hours in the forest, because it's somebody else's car.
- I would get dropped off, probably with Topher.
- I would go in and setup the climb.
- Another way we sometimes do that is we might setup the climb, but not climb the tree. Set it up and come the next day to do the climb.

Gary Paddick (10:36):

- Let's go more into setting up the climb then.
- So you got dropped off for 4 to 5 hours.
- How much weight are you normally carrying in your bag on your back?

Dave Grenell:

- These things we don't know, but I would say, the rope is probably 4 or 5 lbs.
- All the gear would probably come to less than 15. That's a guess.

Gary Paddick:

- So around 20 to 25 lbs maybe

Dave Grenell:

- Yup
- Walk in, go to the tree, and then I would hack a ground cover space.
- I would prepare a flat place I could throw down a tarp, that's relatively smooth
- put the tarp down
- Get out the Big Shot.
- Setup the Big Shot.
- Shoot the line over a branch. That's a lengthy process, depending.
- If you got lucky you could get the line over in 10 mins. If you're not hitting it very good it can take 40 mins.
- Pull the rope over the line and you're ready to clip in and go up.
- Put on the harness, put on the helmet.
- Go through the safety checklist, in terms of being clipped in, stuff like that.

Gary Paddick: (12:25)

- Laying out the tarp, hacking at it, how much time is that? Just an estimate.

Dave Grenell:

- It depends. Say 10 mins.

Gary Paddick:

- For your Big Shot, do you have a standard Big Shot? Do you have it modified at all?

Dave Grenell:

- It's standard.

Gary Paddick:

- Go deeper into the issues with the Big Shot. Is it pulling it and aiming it that's difficult. Getting it over a single branch difficult. Are you isolating a branch, shooting it over a bunch?

Dave Grenell:

- Every tree is different.
- You have to have two people to do it.
- So one person is generally holding the Big Shot and the other person…
- Well you can do it by yourself under good circumstances, but it's hard.
- One person is holding the pole, the other person is pulling the draw.
- Then you shoot it and you try and go up really high. Branches may start over 100 ft. up. Unlike in California.
- It's a lot of…

Gary Paddick:

- Force?

Dave Grenell:

- Yeah. It's you're half a degree off and it goes spinning into never Neverland.
- You're basically shooting a weighted sack of bbs and if it nicks some leaves…little things make a big difference

Gary Paddick:

- No, I talked to a couple of arborists about it and they were all like yeah I could see why the big shot would be a pain in the ass.

Gary Paddick: (14:20)

- In your method though, are you trying to isolate one branch?
    - Dave Grenell: Yup
- There is two of you normally at the climbing site then?

  - Dave Grenell: Yeah
- Have you looked at other kinds of launchers? Opposed to the Big Shot?
  - Dave Grenell: Nope
- I've seen everything from …. some of them use blanks to fire it. So basically you just aim it, have a shoulder stock and just fire it up. They go over 100 ft.
  - Dave Grenell: Yeah, cool.
- A lot of people now, mostly still DIY jobs. There are 1 or 2 professional ones, but they're pneumatic launchers. They can get 100 to 150 ft. range.
  - Dave Grenell: Yeah, I've seen a couple of those. They look really cool.
- Most of them to make are pretty simple. I've made something similar for a school project a bunch of years back. It's just PVC piping and valves.
  - Dave Grenell: Yeah, that would make a lot easier for sure.

Gary Paddick: (15:46)

- When you finally do get the Big Shot line set, I'm guessing it's just standard, you attach the climbing rope to other end of it and pull it over?
  - Dave Grenell: Yup
- Any other gear you're using, like a friction saver?

Dave Grenell:

- Yeah, so there's … imagine you have a hollow tube, which could be leather.
- You're pulling that up and getting it over the branch, <u>which is tricky</u>.
- Then you're pulling the rope through that. Then you're ready to ascend.

Gary Paddick

- Then when you're ascending you have a jumar and a foot ascender?
  - Dave Grenell: yeah
- Do you have a chest ascender?
  - Dave Grenell: No
- Do you have a foot loop for your other foot?
  - Dave Grenell: Optionally, yes.
- Last time we talked you told me about the Tree Monkey Fun group. I looked through their site… there wasn't a whole lot there to see what they were teaching. There was a gear list. Are you using their gear list?
  - Dave Grenell: Yeah, well he helped use source all the gear.
- I know their gear list cost is about $1300…
  - Dave Grenell: We pay $1800 for like 2 people.
- Was curious for base cost.

Gary Paddick: (17:31)

- Have you gone to anyone else to look at your technique (climbing) or different methods?
  - Dave Grenell: No
- A bit off topic, but I've talked to a couple different arborists and one guy was really interested and asked for what you guys were doing, and video, stuff like that, and he

recognized the method better than I could, obviously, and he thinks there are much easier methods
    - Dave Grenell: Ok, good. What would that be?
- So single rope method is a more efficient method of climbing up the tree.
- With a frog walking system, which is basically a rope walking system where you have where you have 2 hand ascenders, a foot ascender, and another system that acts as a foot loop. He was saying for 60-70 ft., he was saying 3 to 10 mins climbing.

Dave Grenell:

- Oh, ok. Sure.
- **Once we get setup, climbing up the rope is not a problem.**
- **It's really the setup, the placement, the location, and the time. <u>The climbing is not an issue.</u>** I mean it's always good to know what others are doing.

Gary Paddick:

- Maybe 40 mins to get the Big Shot line setup.
    - Dave Grenell: If things are going badly, definitely.
- Then setting up the rope itself, once the big shot is up, estimate time?
    - Dave Grenell: 10 (mins).
- Putting on personal gear (paraphrase)?
    - Dave Grenell: 5 (mins)
    - Dave Grenell**: Going up the rope, 5 (mins)**
- I thought the climbing was the difficult part.
    - Dave Grenell: No

Gary Paddick - Go over your system (19:30)

- Isolating over 1 branch, so I'm guessing that's a double rope method.
    - Dave Grenell: Yeah
- So you have a jumar, do you have a friction hitch as well?
    - Dave Grenell: Well you're tied in. I guess I don't know what you mean by friction hitch. There's a couple of knots that act as…
- A stopper
    - Dave Grenell: Yeah
- They slide one way and catch the other way.
    - Dave Grenell: Yeah
- This is one thing, I wasn't sure if you're doing a single or a double when ascending. When you're ascending the loop of rope is getting smaller? Or is the rope staying stationary when you're going up the rope?
    - Dave Grenell: The rope is stationary.
- Alright, I'm still not 100% sure on the method.
    - Dave Grenell: Oh, well, that might be a place to ask Topher. There's two different things we've done. I didn't see him climb in Brazil, so we can ask him.
- Have you done any single rope methods

    - Dave Grenell: Ah, no.
- From what I understand from them, if you used a single rope method, you wouldn't have to isolate the branch, anymore.
    - Dave Grenell: Oh yeah? How does that work?
- Basically what you do with a single rope method is you tie one end to the tree trunk, or another tree trunk. There are different ways to setup the anchor, but that's the basic. You shoot the line up over the branch; as long as it gets onto a branch you're comfortable with it doesn't matter how many other branches it goes over, as long as your main point is strong. Then you ascend up this rope, probably kind of similar to what you're doing, or with or single rope methods. The simplest, or most basic, is a foot locking method that uses no gear, up to a frog walking system, that's like a $200 system that you just kind of walk up the rope.
- One of the benefits of it, is that if you have a ground person you can set it up that if anything happens, the ground person can do the lowering for you.
    - Dave Grenell: Yeah, cool.
- Adds to the safety as well.
- (Explaining advances in SRT with new gear (i.e. Rope wrench or hitchhiker)
    - Dave Grenell: I see, cool.
- Just one thing to think about because it might solve some of your problems quicker, for next time.
    - Dave Grenell: Yeah

Gary Paddick: (22:40)

- You climb up the tree. As you're climbing, I'm assuming you're looking out for falling objects, or other hazards as you're climbing.
    - Dave Grenell: Ah huh, yup.
- Are you climbing up with all your gear? Or do you haul the gear up afterwards?
    - Dave Grenell: I go up with all the gear.
- And is that weight a problem, or is it light enough that it's not really….
    - Dave Grenell: No, not at all.
- What gear are you taking up with you? The device obviously, but…
    - Dave Grenell: The device. Sometimes a hammer. A screw gun occasionally. Some lanyards, something to loop around the tree, so you can bring yourself in close. That's about it.
- A rappel device, throw bags?
    - Dave Grenell: Um…yeah! I mean you can let yourself down.
- I'm guessing you're not re-setting lines up in the tree?
    - Dave Grenell: No
- You talked about before that you have problems sometimes when you get up there, you're not close enough to the tree trunk. Is that correct?

Dave Grenell:

- Yeah. If the angle is bad, then you need to throw a lanyard and pull yourself in.

Gary Paddick:

- OK, but you're solving that solution in the tree?
    - Dave Grenell: Oh, yeah.
- Ah, ok. Sounded before like you might have been climbing down, and re-setting each time.
    - Dave Grenell: No.
- So you have horizontal movement pretty much down, at least for your needs.

Gary Paddick: (24:25)

- One thing I would like to get an idea of. Once you get everything setup and you're climbing the tree, how often is that tree; that climb; good? Is it 1 in 4? Half the time?

Dave Grenell:

- What do you mean by good?

Gary Paddick:

- You get up, install the device, come down, and that one's done.

Dave Grenell:

- Oh. I don't think we've done enough to establish that.
- Dave Grenell: You know, I think in Brazil. In Africa we would set them up, and… Yeah it really depends. If the network connectivity is good you don't need to go back up.

Gary Paddick:

- OK, so your max climb height; you're still trying to install at the 60 – 70 ft. mark? Are we going higher now?

Dave Grenell**:**

- **As high as it takes.**
- Assume that many trees the branches don't start for a 100 ft. So you're anchoring to that branch<u>, but the higher up **maybe** the better the connectivity</u>, so it's better to be able to go high.

Gary Paddick:

- I was thinking not even for climbing, but for a ground installation method; just trying to think how high would you have to get.
- One simple method could be a really long stick. It sounds silly, but it could be a method, right.

Dave Grenell:

- Yeah, yeah, yeah. Yeah, that's perfect thinking. Yeah, exactly.
- For low mounting a device, that would be a test; that would be perfect.

- Just like yeah, throwing a stick up there and finding a way to stick it onto the trunk. That would be great. That would be really good.

Gary Paddick: (26:15)

- That's why I kind of need the range.
- I found one the other day; it's for military purposes, but it's an aluminum pneumatic extending pole that goes 15 m, which is like 50 ft.

Dave Grenell:

- Range necessary to **test** a device?

Gary Paddick:

- Well for installation. That's the main goal right?

Dave Grenell:

- Well, so there's no….so in Africa it might have been 50 ft. In other places it might be 20 (ft.).
- The whole point is the level of connectivity, so if you can get good connectivity at 20 ft., there's no reason to go to 80 or 60 (ft.).
- In Ecuador, where we're going next, there's supposed to be great connectivity. So Topher will probably want to go higher, just because he likes that. But we wouldn't need to. It would be really great to have a pole where we could deploy a bunch of these really fast for testing.
- The methodology is usually, assume you're going to have to go back and get the thing or re-jigger it, before a permanent placements.
- **It's as you're saying, but something up temporarily. Be able to come back when you know, "ok, we're going to keep that location, and now we're going to go for a higher, more difficult to access placement."**
- A 15 m aluminum pole that you could; that would be awesome

Gary Paddick – Height Reasons: (27:59)

- When you go for a higher placement, is that because higher equals more signal, or for other concerns, like other people getting at it?

Dave Grenell:

- Primarily it's for higher equals more placement.
- Secondarily higher can equal more sunlight for the solar
- and if your first branch starts really high up in some trees; those trees aren't ideal for camouflage because that means you're putting it kind of on a bare trunk, so you have to camouflage the device as a fungus thing on the trunk.
- Versus if you get up higher it's easier to hide
- The final thing, this all assumes that we're doing everything in testing, but where we're going is we're not doing any of that. We're doing the first installation and then the partners are doing everything else. The partners… we'll train a partner to climb

trees, but they're not going to want to do that. They're going to want to do something more radical and easier. So it could be like the pole or a hexcopter, or something else.

Gary Paddick:

- Is that because of the radical factor?

Dave Grenell:

- Because they're going to want to be able to expand the system.
- **A lot of people aren't going to let their employees climb trees, because it's a liability to them**
- **If you're climbing trees regularly, you're good, but if you do it once every 5 months you could hurt yourself because you're not doing it enough to really remember everything.**
- These people, the people we work with, you can train them, but they don't pay attention to training protocols. They just do it.
- For **rapid expansion** the answer will be…the pole is a very good idea, **because that's easy.**

Gary Paddick: (30:10)

- I don't mean to be crass with it, but is there concern with safety your concern from a liability point of view?

Dave Grenell:

- Well, imagine if someone got hurt. That would probably kill the program.
- We're never going to be sued, it's just they … **there are always people in these organizations looking for reasons not to do something.**

Gary Paddick: (30:50)

- The sunlight, is that being a major factor right now or is it mostly solved? Is the power issue mainly figured out?

Dave Grenell:

- Yeah, in Africa it wasn't.
- In Brazil it has been.
- The devices are now streaming 24 hours a day. That's working really good.
- It's much improved and will continue to be.

Gary Paddick:

- Back to climbing; have you had many close calls or something you can recall

Dave Grenell:

- No
- I mean I've been swarmed by insects up a tree. That kind of sucks.

Gary Paddick: (31:51)

- You're up in a tree, installing a device. Do you normally clip in with a lanyard when you're installing a device? Or some other method to get close to the tree?

Dave Grenell:

- Yeah, I usually use a lanyard to get close to the tree.
- You basically… need to be right on the tree, so even if you're 6…if you're hanging from a rope and your placement was great, which it's not going to be, you might be 6 inches from the tree but you need enough counter leverage to be able to do a screw gun or do a hammer, so you really need to be clipped into the tree.

Gary Paddick:

- That seems like a pretty standard thing anyway.

Dave Grenell:

- Yup

Gary Paddick:

- Have you ever had problems getting closer? When you're up there do you have problems getting the lanyard around it or getting close enough to get the lanyard?

Dave Grenell:

- It hasn't been.
- It's definitely throw it around the tree and grab it.
- It's kind of a stupid way to do that, but it works fine.

Gary Paddick: (32:46)

- Attachment methods. (I list off the falling from interview guide:) Anything else?
    - 3D printed mount
    - Nails
    - Horseshoe shaped nail
    - Zip ties
    - Steel or copper wire

Dave Greenall:

- No, that's it.

Gary Paddick:

- Are you guys still looking into attaching it to tree branches or are you still pretty happy with the tree trunk?

Dave Grenell:

- Yeah, I think the branches would be good.

- I think we're both totally open to trying vertical and horizontal mounts.
- It could be on top of the branch, facing the sun.
- Currently everything is perpendicular to the tree trunk. But we would try anything

Gary Paddick:

- How thick are the tree branches? Are they arm thick, leg thick, bigger or smaller?

Dave Grenell:

- There's all different kinds. The kinds you want to cast the line over are 12 – 14". We've done others, we've done smaller things.

Gary Paddick:

- If you got up there. Say you climbed up that branch that was that 12-14", before attaching the device would there branches that are smaller that you could get a hold of?

Dave Grenell:

- Yeah. If you went up to where the line is secured, to the first branch… if you were going high enough to step on a branch you would do that. That makes life a lot better.
- Instead of hanging off the rope you're now climbing a tree, and then you have a lot more freedom of movement.
- There are…I haven't seen cases where we're mounting the device on the branch. So far it's mostly on the trunk and it's angled towards the sunlight is. If there's leaves in the way you might cut those down.

Gary Paddick:

- I was thinking of different self-attaching clamps, but without knowing what that diameter is, it's hard to…

Dave Grenell:

- Yeah, totally. That's a really good idea. That's where it gets tricky.

Gary Paddick: (35:24)

- You say you're stepping on branches potentially, but are you still mainly installing below the canopy, or are you going into the canopy, above the canopy.

Dave Grenell:

- Well both.
- I mean in some cases we install below.
- In some places in.
- But, there's almost always canopy… when you're in it there's always shade either way.

Gary Paddick:

- What's the most frequent one right now?

Dave Grenell:

- The most frequent one would be one the trunk. In Africa they were all below the canopy, in Brazil they were in the canopy.

Gary Paddick:

- Is that because in Africa you were on the road, so you had broken tree cover or?

Dave Grenell:

- No, that was just because our rope wasn't long enough and we didn't think we had to go higher.

Gary Paddick: (36:25)

- Earlier you were saying one of your easier ways (for testing) might be to take one of the refurbished cell phones, put it in a hexcopter and fly it up, and get the readings. Are you using some sort of app or program to take these readings or record them?

Dave Grenell:

- Yeah.   You can ask Topher what that is.
- I mean in some cases the answer was no, we were just looking at how many bars of cell service.
- Looking at it more, I mean the phones are able to communicate more info than that.

Gary Paddick:

- What I was thinking, would there be an easy method or is it already in place where you could get the readings on a second phone down on the ground.
- If you have the device up on a stick, or a drone, or however it's up there, and you're trying to figure out how much sunlight or cell signal it's getting, can you read that from the ground?

Dave Grenell:

- That's a good question. I don't know.

Gary Paddick:

- For me looking at solutions, I don't have the skill or ability to make that program.

Dave Grenell:

- Yeah, Topher…we would find someone.

Gary Paddick:

- I'm sure it's not that difficult

Dave Grenell:

- Yeah, that's probably. We do want to do manual data offloading.

- What that looks like is, if the device is 40 ft. up, someone can go stand under the tree and just take the readings.
- Create a Wi-Fi connection or whatever. We wouldn't be able to work on that until after June.

Gary Paddick:

- Is that something that could be worked on? The way I see it, any method where you're not personally putting it on the tree there needs to be some way to know the readings down below
- . If you can get it real time while you try to place it that would probably make it easier, because if you install it up there with no easy way to get it down, then you're going to have it stuck.

Dave Grenell:

- Yeah

Gary Paddick:

- Same thing with the pole. If you put up with the pole and it's nailed in, and you it doesn't get the right readings, then you're like, "Oh, crap. How do I get it off?"

Dave Grenell:

- Yeah, I think we probably…. we wouldn't put it up on the pole unless we had good reason to believe the readings were pretty already good. Totally.

Gay Paddick: (38:44)

- You installed it in the tree, it's nailed on or screwed on…, I'm guessing you're checking the device while you're up there to see if it's getting the right levels; cell phone signal and sunlight.

Dave Grenell:

- Ah, no. You would do that back at the base.

Gary Paddick:

- Ah, ok. So you don't do any checks in the trees with it?

Dave Grenell:

- Generally. You might.
- In Africa we didn't.
- In Brazil I think we did.
- The whole point is to put it up and then measure what's actually happening over the course of a couple of days back at the base, in terms of…
- The cell network might go down at certain times.
- Most of the important readings happen back at the base.

Gary Paddick:

- Was that before your first stage kind of thing where you're not putting them up not too high to just get the first reading or was this at all stages; even your second permanent installation?

Dave Grenell:

- Well in Africa, putting them up not very high, we just weren't able to get much of a signal, so we needed to go higher.
- And we learned that late.
- In Ecuador we probably won't have to go up very high, which is great, but I think that Ecuador does not represents remote rainforests.
- So in most places we're going to have to go up high.

Gary Paddick: (40:00)

- Ok, so must checks are done at the basecamp.

Dave Grenell:

- Yeah. By checks I mean, you can't get enough diagnostic information by being there for an hour.
- So you need to get information over the course of like; how are the power consumption running over the course of a day or two.
- You know, sunlight; yeah.

Gary Paddick:

- So you place it (the device) in the tree, come back down the tree.
- Rappel and lower yourself down the lines.
- Do you guys have any steps to do that, or do you just lower yourself down off your current setup?

Dave Grenell:

- Yeah, there's no steps.
- That's pretty easy.
- You come down, and just pull the rope through and coil it up and put it back in the bag and pack up and leave.

Gary Paddick: (441:00)

- Since you guys got dropped off from the vehicle you're probably moving on to your next site.

Dave Grenell:

- We would probably do one, yeah one general area in a day, if we were doing installations.
- We would try and do 3 installations, within a couple of miles.

Gary Paddick:

- How far are you walking normally?
- Trying to think of difficulty walking with gear.

Dave Grenell:

- That's never been a problem (carrying gear), but if we get dropped off, we're walking about a mile.

Gary Paddick: (41:45)

- I know you keep saying you want quick, because that makes sense, but it would be good if we could figure out a time goal.

Dave Grenell:

- For installation?

Gary Paddick:

- Yeah. Getting to the tree, getting your gear out, putting it up in the tree, packing up and going on.
- Just to make it easier for evaluating methods and getting a better picture of what's need…

Dave Grenell:

- Yeah, totally.
- **Although we're not super worried about that (installation time),** because really the whole program comes down to what our partners are going to do.
- We can slog it.
- Other people aren't going to go through these steps because the steps are… it's just difficult.
- Native people, they're not into climbing trees, so far as I can tell.
- They might be if they had to, or you're paying them to.
- When someone comes to us and says, 'How is this system scalable?' it's not scalable with people using arborist techniques to go up a tree, probably.
- One of the long term, it could be a science fiction answer, but when someone says, 'Ok, how are you going to protect a 100,000 sq. km of rainforest in 3 countries and scale that up to a million (1,000,000 sq. km)?
- The answer is going to have to be….kind of like, you sent me that hexcopter video. Showing someone something like that helps them imagine a future where there's more money, and more investment in that process.

Gary Paddick:

- How real does it have to be?
- Just thinking off the top of my head. If you were using the stick, like a pneumatic pole, to do the original low installations, but then still needed to do the arborist techniques to get to the higher…

Dave Grenell:

- I think that’s the best idea I’ve heard so far.
- It doesn’t have to be super real in the concept stage
- People just want to see that; they want to hear something that sounds probable, and will work on one level. They understand there will be problems with it.
- Even being able to shoot… imagine if you have, a bolt action thing that would shoot a hook into the tree, that you can put the pole and hang the device off it. That would be great.

Gary Paddick:

- So you shoot a hook up into the tree. Does the hook have a line on it?

Dave Grenell:

- Just a hook. Imagine you’re shooting a bolt into the tree, and it’s got something that you can hang the device on.
- So then you just put the pole up, hang the device, take the pole down, and then it’s just hanging there.
- Then you could put the pole up and take it off the hook. Bring it down.

Gary Paddick:

- So you think hanging the device would be an ok solution?’

Dave Grenell:

- I do.
- As a temporary solution, absolutely.
- As a permanent solution, in some cases.

Gary Paddick: (44:53)

- You’re back at base camp, probably taking readings, probably cleaning up your gear, checking for maintenance; that sort of stuff.

Dave Grenell:

- Yup

Gary Paddick:

- When you are testing your system back at base camp, what’s the biggest thing? Is it just checking for signal and power, or is it more bug testing going on, or what sort of things are you looking at?

Dave Grenell:

- Yeah, the biggest thing is usually how much data flow is getting through.
- We’re trying to stream 24 hours of sound.
- So, in 24 hrs how much are we getting, is the information live streaming or is it backed up and re-sent latter in packets when there’s more connectivity.

- How much power consumption.
- We can measure all that stuff on a backend console that looks at each device.
- You can click on a location and see what the heat of the phone is.
- We can see the data flow rate.
- We can see how much information we're getting.
- We can see when the network went down, sometimes there's a lot of cloud cover and maybe the network goes down at weird hours.

Gary Paddick: (46:15)

- When you are installing in the tree, thinking from a pole or something that climbs up the tree itself, how well do you think you can spot a good installation spot from the ground, or would you need video from up there (install location)?

Dave Grenell:

- For a permanent installation you really kind of need to be up there.
- For something that is not permanent you could definitely see it from the ground.

Gary Paddick:

- Say you had a drone, or a pole, or whatever for a permanent installation.
- You were saying you would probably need some video feedback to be able to see where you were putting it.

Dave Grenell:

- Say that again, sorry.

Gary Paddick:

- I'm thinking, if you were doing your permanent installation and the end of this 20 ft. or 60 ft. stick, or 70 ft. stick, you're going to want some sort of video on the ground to see where you're placing it. Whether that's coming from the camera in the device or some other camera device.

Dave Grenell:

- Oh, that could be interesting.

Gary Paddick:

- Or would a guy on the ground with binoculars be good enough.

Dave Grenell:

- I think the method of affixing device to the tree would probably need to be easy enough that you wouldn't have to rely on an optic camera feed to see what you're doing.
- But it's a really neat idea, and there could be…. I don't know.
- I think it's got to be really simple. I think my first answer is that it shouldn't rely on that.

- But yeah, at 70 ft. up you're not going to be able to, if there was a hook that you shot up there or something, you're not going to be able to see that from the ground.
- So, it depends on what the methodology of hanging or fixing the device is.

Gary Paddick:

- I was thinking even just for, picking a good spot on the tree trunk that has sunlight.

Dave Grenell:

- **Yeah! That's how we do it!**
- And I usually see that from the ground. Well so far.
- Once you get up there things can change pretty fast though.

Gary Paddick: (48:35)

- Other activities with partners on the site.
- I know from the Tembe report there's some training, and you're talking about training some tree climbing.
- So what other activities do you do with your partners I guess?

Dave Grenell:

- Well the reason they would be trained, let's say, the device stops working in Brazil. We don't want to fly down**.**
- **So they need to be able to get it.**
- Topher trained a couple of the Tembe to climb and retrieve devices; they haven't had to yet. But the real reason for partners is to be able to expand the system.
- So basically we want to create something that's off the shelf, that I can just send you 100 of them and you can put them up. Yeah, that's the goal.
- In most cases assume that our operation plan is setting up each new country requires us to go on site.
- So maybe we send you.
- You're getting paid to do the pilot, which is figuring out what the local problems are in these methodologies.
- Running network diagnostics.
- You know you need to buy data plans from each country.
- The data plans are different.
- The networks are different.
- Once you figure that out, then you're done, and you can start sending them devices and they can put them up.

Gary Paddick:

- You do the original install, the original setup and they do the expansion.

Dave Grenell:

- Yeah, because we're figuring out the problems. If there are any and then we're training them.

Gary Paddick – RFCx support post pilot: (50:25)

- The support given by RFCX once you guys have left (reading off interview guide question) is probably replacement parts/device, computation, compiling of records, anything else you would do?

Dave Grenell:

- (Confirmations while reading list)
- Yeah, I mean the main thing is we're looking at the data and we are watching to see how many alerts they are getting and if they're responding to those alerts.
- So it's the oversight piece is, OK you're getting alerts, but if you're not responding to them, it's not a useful system.
- Then it becomes a matter of transparency.
- They get an alert and there's a process where they record what happens, whether they responded.
- Maybe they don't want to respond, maybe they're looking for forensic patterns of activity.
- That's very true for many of our partners.
- It's kind of, 'what are you doing with the data?' is a big part of our time.
- How are you using it strategically, what's working, what's not working, because every time we go out after that…
- We want to collect the stories. How it's working and how's it's not working.
- So 20 countries have invited us to do installations.
- 20 countries, of those **we've chosen 3 based** on them having good partners and some infrastructure and what we can afford to do, but most of those countries don't have money.
- It's like an NGO who works there in Malaysia and say, 'hey, come set this up!' and you know the cost is $100,000 and they don't have any.

Gary Paddick – Questions from the Tembe Report: (52:15)

- So you have the new antennas (directional). Is that looking like a long term solution?

Dave Grenell:

- That's a long term solution, yeah.
- You know the devices are kind of modular, so if you need to fix an extra piece to it.
- So we'll say there's the basic module that has a little tiny antenna.
- The basic module might not even have solar panels, it may have a battery pack.
- Sometimes you don't want real time connectivity, you want to use it like a camera trap.
- Someone is going to go check on it every three weeks and download the data.
- Some people when living streaming it will have solar panels and be up in a tree, not be like a camera trap.
- The directional antennas are going to be if you need to connect to something far away, like 30 to 40 kms away. And I think, yeah, I think we're going to use those.

Gary Paddick:

- If you’re going to use those I’m going to need an idea of the weight, or how it’s affecting the base.

Dave Grenell:

- Well, that’s a great question.
- You’re have to ask Topher that one because I’ve never set up a directional antenna.
- What I’ve seen…the directional antenna is mounted in the tree, so that’s a case where you would want to be in the canopy I think.
- I don’t think he ever puts them on top of the device, but I could be wrong.

53:55

Gary Paddick: (53:55)

- With the devices have had any fail because of animals yet, or insects, or moisture?

Dave Grenell:

- Nope

Gary Paddick – Would like to dig deeper into the problem: (54:20)

- So the climbing the rope isn’t actually that big a problem?

Dave Grenell:

- Right

Gary Paddick:

- Setting the line is a problem by the sounds of it

Dave Grenell:

- Yup.
- Well climbing the rope is just a very unideal way to… Going up a tree… Sending a human being a 100 ft. up is just a very unideal way to do this ultimately.
- If you talk to people who are like, ‘we’re interested in supporting your solution, but only if you can scale it,’ as soon as they understand that you’re going to have to send a human being into each tree, they become sort of disinterested.

Gary Paddick:

- So why is that? Let’s dig deeper into that.
- In my mind that’s the simplest solution, obviously why you guys are doing it.
- I’m just trying to get all the problems of why that isn’t a good solution.
- Why isn’t that scalable, because in my mind, and I’m probably thinking wrong, but if I talk to any one of my colleges here, the thought process goes: well, you’re installing it most likely in the 3rd world or developing countries.

- You're labor probably isn't that expensive and if you're not on the ground anymore doing the pilot; if it takes you an extra two weeks to install it all (the system), then it would still be cheaper than a high tech solution.
- So I'm trying to see what the issues would be, right?

Dave Grenell:

- It's highly, highly, highly labor intensive.
- It takes too much time.
- The dangers and the liabilities.
- I don't know, lot of our partners, once they see it, are "oh, I'm never going to let my people do that," because they're responsible for what happens to these folks and again we…
- You can train someone, but the cultures are…that we're dealing with they're kind of a hot shot cowboys cultures.
- A lot of people don't want to climb trees.
- Their very lazy as well.
- This is like a highly effort bound exercise.
- I can tell you one thing, all these folks go shit giggles gah gah over new technology.
- So like the hexcopter and stuff, that's like a video game for them. They can't believe it. They will do that all day long.

Gary Paddick:

- One of the things I looked into were the auto ascenders. There are a couple of them out on the market.
- The coolest one you're not going to get because it's military grade, but it's basically a batman grappling gun.
- You fire up, attach a little system to it and pulls you up in; most of them are around 10 m/s.

Dave Grenell:

- Yeah, that's pretty cool.

Gary Paddick:

- Would something like that be appealing or is it still not safe or still too labor intensive?
- Like where is the labor intensive coming into and where's the push back coming from, what part of the process?
- I talked with one guy and he used to setup zip lines in Blaise and he was jealous of your project because he wants to get back into trees basically…. He said what he would do that would be easiest is you could setup a system kind of like the SRT, but it's got a false crotch.
- So you basically you send the first line up, don't have to isolate the branch. You pull up a pulley on the end of it and that acts as your double rope system.

Dave Grenell:

- Mmm hmm. That's good.

Gary Paddick:

- He would take a riggers winch, off a sailboat and he would set it up where it's safe.
- Then he would just use a power drill and that would be enough to pull the person up the tree, within a few minutes.

Dave Grenell:

- Oh, that's really cool

Gary Paddick:

- Right? It's really simple, and really cool.
- He was like if we had that setup when we were installing the zip lines it would have saved us so much time and effort, and it would have been the cat's ass.

Dave Grenell:

- I think, if our partners are going to be tree climbers they should do something like that.
- **That would be a really great recommendation**.
- The issue with sending someone up a tree for scaling is there are so many variables in terms of the placement, the tree, the sunlight.
- If someone is really able to understand and digest that, which I have not seen.
- I think what happens is, it's very likely partners are putting them in trees and then they're (devices) not working very well or there's a lot more failures because they didn't angle it quite right or they did it kind of fast and sloppy.
- They're going to be not inclined to go up and get them, just because it's a pain in the ass.
- But if you could do this hook thing, or create a way to shoot something into the tree or place a thing and then there's just a method to get the device to hang over it in a variety of ways.
- They're going to be much more interested in that because it might be easier to get it down.
- As long as you don't have to…sending someone up a 100 ft. is never going to be ideal.
- Also there's a lot of trees we would use, but they're not easy to climb.
- I mean, let's say you're trying to monitor a certain area. I would say 90% of the trees are not ideal for climbing, for sending a human being up.
- But if you were using the system with like with the pole, or something, all of a sudden 80% of them are good.
- You start with a 100 trees you're going to be able to climb 10 of them, whereas if you have another way of doing it you can climb 70 of them. Well not climb, but install.

Gary Paddick: (1:00:53)

- Is that because of hazards, tree rot, insects, or just not big enough trees? What's the…

Dave Grenell:

- It could be lots of different things.
- Sometimes there is no sunlight there, so it's too dark.
- A lot of times the branches that you are going to shoot over are too small, they might not hold you.
- Or they're too high up.
- Trees in the rainforest are not like a pine tree where there's a beginning and an end.
- A lot of the trees, it's like they have a 100 years of stuff and they kind of merge into the canopy, so you're climbing on something that's covered with vines, and dirt, and insects.
- We don't want to go up those because you can't really see if it's safe.
- You can't see if the tree is rotting or not because it's just covered in growth.
- A lot of the trees are too big.
- The branches might be too big for us to put the thing over.
- That was a stupid problem we ran into.
- So like a really, really big branch we would put the thing over it and the rope would be abrading on the sides, so we just needed a longer cable.
- **That's why you're idea with the pulley is a great idea.**

Gary Paddick:

- That problem there, a single rope system would solve that problem too.

Dave Grenell:

- Yeah, that would be good.

Gary Paddick:

- With a single rope system the rope doesn't move. You move on the rope.
- It makes it easier.
- It's the most efficient for going up because one, you don't have to worry about friction anymore because it's not moving on the branch.
- Two, if you have a double rope system with a loop, every time you pull a foot you're only moving half a foot. With this one here you move the foot.

Dave Grenell:

- Yeah, it could be good.

Gary Paddick:

- That gross tree you just talked about. Are you still contacting the tree while going up it?

Dave Grenell:

- Sometimes yes, sometimes no.
- Mostly no.

Gary Paddick: (1:03:19)

- The problem when you're scaling, and you're partners are doing it, they're doing a half asses job.
- They could install it where there's not enough sunlight, or not enough signal. This kind of stuff.

Dave Grenell:

- Well mistakes are costly.
- It needs to be as simple as a camera trap.
- You walk on a trail, you place it, you hide it, and you walk away.

Gary Paddick:

- I'm just thinking is putting it on a hook going to solve that problem.

Dave Grenell:

- Oh, I don't know. I think it might, I don't know.

Gary Paddick:

- At the moment, it doesn't sound to me that remote installation is going to solve issues of placement.
- That seems to be one of the harder parts of an auto or ground install system; placement in the right spot.
- Seems to be the biggest reason to have a person in the tree is because they can do that.

Dave Grenell:

- Yeah. **I think as the device gets better placement becomes less an issue**, hopefully.
- At the moment… it was a huge issue in Africa.
- I think it's becoming less of an issue as we go.
- In Ecuador it should not be an issue because they have great infrastructure, but we'll find out.

Gary Paddick:

- I know this ones sounds simple, and probably doesn't work because of the money factor, do these places have arborists?
- Have you looked into that? Just for scaling up.
- Thinking that if this was in the US, you're installation method probably wouldn't be your limiting factor in selling this product.

Dave Grenell:

- These places do not have arborists because we are not usually in a city.

- You don’t find arborists in a jungle in Africa or Brazil, they don’t have that.

Gary Paddick:

- I mean if you hire them from the main cities for the week of installation.
- Not for the pilot, but for scaling up.
- You’re partners on the ground have already selected the sites, like you said they do for you and now you bring in 2-3 guys for 1-2 weeks of intense installation.

Dave Grenell:

- I mean we would probably eventually try and hire an in country engineer who deals with all the maintenance issues, all the engineering, all the training, and all the placement, someday. Yes.
- And they would float around, this would be what they do.

Gary Paddick:

- Thinking of your workforce in the future, have you looked into volunteers to do the installation?

Dave Grenell:

- No, because…why would we do that?

Gary Paddick: (1:06:21)

- I was just thinking, one that I’ve seen are these turtle sanctuaries, in South America.
- That just run off people from NA that are between 20 and 27.
- They go on their holidays and they rather go work on a turtle sanctuary then just go on a resort.

Dave Grenell:

- Oh, yeah. No we wouldn’t do that, at least for installation.
- It’s a lot of training.
- There’s a cost to train people.
- People can get hurt.
- They’re going to do it potentially badly.
- You have to know where the devices are.
- **It’s hard for us to find them as we put them up**.
- We might do volunteer stuff, but we probably wouldn’t rely on a volunteer army to put them up trees.
- There are other thing people could do that would be really helpful. I don’t know what they are, but we can figure them out.

Gary Paddick – Back to the key problems: (1:08:20)

- Scalability.
- People don’t want to be 100 ft. up in a tree, mainly because of safety and they don’t think it’s scalable.

Dave Grenell:

- Yup

Gary Paddick:

- And there's no wow factor.
    - …. (some confusion, but goes into explain why there's no wow factor)

Dave Grenell:

- No, and here's why. You should come down and do it, because we're talking about theory and it's hard to get a real picture of what it tastes like, but what it tastes like is imagine it's 108 F.
- You've been walking around the forest, things have been biting you.
- You need more water than you brought.
- You're hungry, and maybe you have a little fever cause you don't feel very good.
- There's… all the other factors of being in a remote, tropical rainforest that are not helpful.
- You're sweating bullets, there's ants that are crawling all over you. There's flies in your eyes.
- When you're trying to tie these things you're being attacked by flies that are flying up your nose.
- You can make a mistake because you lose your concentration.
- You're tired, if you've done it for 3 days in a row, you're just tired.
- I would say a lot of the limitations are the environment itself is punishing.
- The rainforest wants to kill you. Ahh haa haa. Stuff like that.
- I mean for locals too. Ha ha.
- There's no trails in the rainforest because they want to cut it down if anything.
- If they're getting paid to go through it fine, but I's an unpleasant experience.

Gary Paddick: (1:10:38)

- Back to the installation method. Trying to get the real key, it needs to be this, needs to be that. What the real problems are coming from.

Dave Grenell:

- Yeah, I think this is a good exercise. You'll get the full 360 degree.
- Our assumption is that the way this could be done has nothing to do with the way we're currently doing it, so the problems we're trying to over….
- Overcoming them might be a system that's much better, but isn't the ultimate solution in terms of, really thinking of something weird.
- It can be really weird, you know.
- The devices are currently in boxes, they could be in a pouch someday.
- The solar panels are attached to the box, maybe they don't need to be attached to the box or pouch, just a wire from one to the other.
- **It could be completely conceptual, science fiction.**
- Throw it out of a drone, drop it out of a drone or helicopter.

- One thing we like to do is rely on tools that others are getting excited about.
- What's the total weight of this thing, I don't remember, say it's a couple of pounds. Is there a hexcopter that will float something this big, I don't know, but we can probably make one.

Gary Paddick:

- Well there is, but it's all cost.

Dave Grenell:

- So that's one time cost, because we would use that one thing to do like 30 placements. So that could be interesting.

Gary Paddick:

- You're probably looking in the 50-60 grand range.

Dave Grenell:

- Oh shit. For a hexcopter!?

Gary Paddick:

- For a good drone, for what you need.
- I've only done some quick searches on it and they go from $200 to $100,000.

Dave Grenell:

- Yeah, I'm not excited about drones at all because they crash, and you have to be really good at flying them.
- And our partners would be flying them, and they're just not that useful.

Gary Paddick:

- And most battery life is 20 -30 mins.

Dave Grenell:

- But the hexcopter thing, because they can float vertically up a tree, they're easy to pilot.
- I like that video you sent.
- I hadn't seen anyone pilot them in that dynamic a way. Tying a thing around.

Gary Paddick:

- That wasn't piloted, that was auto right.

Dave Grenell:

- Ah, cool. That's neat. I think those are fun things to think about.
- …. (talking about thesis plan)

Gary Paddick:

- The development stage of a concept into a product, that alone could take a year.

Dave Grenell:

- Yeah, I think it needs to be simple enough, that hopefully it doesn't require.
- The simpler the better.
- Because the concept is key for the scalability piece, coming up with those key shiny apple concepts as early as possible would be helpful because we are talking with funders.
- So they're going to ask. Doesn't have to be what we finally go with, but… like the **pole, that's a great idea**. Just super
- The simpler, and it can be stupid. That's great.

Appendix 3.2: 2015-12-14: Project Overview with Topher White and Dave Grenell (Highlights) – Part 1

Interview with Topher from RFCX

Part 1 - January 4, 2016

The conversation to this point was the first of 2 parts completed that day (a required room change broke up the conversation). The conversation to this point was the confirmation and discussion of the written project plan that was sent RFCX.

Note: No customer needs in this part of the interview.

All quotes by Topher, unless otherwise noted.

Conversation Participants:

- Topher White (RFCX)
- Dave Grenell (RFCX)
- Gary Paddick (Aalto)

Recap:

1. The written plan that was sent to them was clear and they are happy with it.
2. They are happy with the final outcome being 1 or a few concepts for them to try out.
3. They like trying a lot of new things
4. They can see this continuing after the thesis. (Implementation outside the scope of the thesis).
5. "Giving you the freedom to limit your scope and in fact encouraging you to limit your scope…"
    a. "Don't be responsible for changing everything."
6. There are a lot of installation tasks.
    a. Still in pilot phase (testing). It's quite possible that all the installation steps will be needed for future installations.
    b. They are happy with a solution to 1 or 2 of installation task.

    c. Don’t need to incorporate all those tasks into a solution.
7. “Getting it up in the tree is what takes the most time in the field.”
8. They are happy to be active in the concept screening process and see value in learning such a process for themselves to combat (outside) idea fatigue.
    a. “Having that sort of framework for how to deal with a lot of ideas that you’re laying out for us is, to learn from you… “
9. Things change completely in the use environment versus test environment.

Topher White: (0:23)

- Thanks for sending the whole write up (project plan).
- I read through the whole thing a few times.
- It definitely makes sense.
- I’m very impressed that you’re capable of coming up with 50 ideas, for anything.
- ….
- **If you come up with 5 ideas, of which 4 are good, that’s fine.**
- **Or if you come up with 5 ideas in which 1 is good, that’s also good.**

Gary Paddick:

- That’s the goal realistically.

Topher White: (1:40)

- Tell me a little bit more about the main goal that you see; that you plan to design for this. Is it like a mounting mechanism or mounting technique?

Gary Paddick: (2:25)

- I’m seeing it as an installation method.
- It could be a mounting mechanism or it could be a mounting technique.
- The main problem I’ve been focusing on is how to get it into the tree.
- One of the challenges was how far do you take that. Is it with the whole mounting or just getting it up there vertically?

Topher White:

- Hmm, you nailed it.

Gary Paddick:

- With the plan I sent you, the idea is that; when I spoke with my prof about it, and what would work on the thesis side for me, would be that it’s more of a product development and concept development project. From the school point of view.

- *Explaining the method described in the project plan*

Gary Paddick: (3:35)

- One thing I was a bit concerned with for you guys is that it wouldn't necessarily include detailed design, at this stage.

Topher White:

- **That's okay.**

Gary Paddick:

- End of the thesis is here's what we think the best way forward is and this is what we should start developing, but it's not the actual development, detailed design, or prototyping of it.

Topher White:

- **That is actually still quite useful to us. In many ways it's better than you at a great distance, deciding on something, going through the effort to prototype it and putting it in place.**
- Basically designing something from your imagination versus putting it in the field.
- … (some talk of the amount of time put into it)
- It doesn't have to be entirely finished within the scope of your thesis.
- **As long as there are some concepts in place that we can sort of test and keep in contact with you, keep sort of rolling it out. This will be your responsible for as part of the project. Something that you invented.**

- (Talk of Pennsylvania group – tree climbing robot)
  - Very ambitious.
  - Doing it entirely in an ideal situation has nothing to do with what's in the field.
  - **Totally different once you get out in the field.**
  - **Important to test one step at a time. Or maybe multiple steps you want to put together.**

Topher White: (6:22)

- **There's a lot of steps to the installation at the moment.**
- **Getting it up in the tree is what takes the most time in the field.**

Topher White: (6:50)

- Installing the device up in the tree. Bringing the hardware. Attaching it to the tree. Solar panels. Doing some diagnostics to ensure that it's working as you expect. In a most of cases we also attach an external antenna. This are some of the steps, and sometimes there are other steps sometimes as well. These are some of the steps that we take into account, that I consider critical at the moment to the installation. These (installations) are all a part of the pilot project. Those are the types of things that are hard to do at distance, that's why getting up in the tree is something we rely upon right now to be able to do all this stuff in hand with the devices.

- But that doesn't mean it has to be the case for all the installations.
- Doesn't mean that what you design has to incorporate, has to take care of all those things automatically.
- **If it does one of those things, or if it does any two of those things, or if it simplifies the process, or makes it easier for us to get up or get the device up there; or if it's easier to get the antenna up there or position it.**
- **Those are all like very, very significant contributions to the overall process.**
- **Giving you the freedom to limit your scope and in fact encouraging you to limit your scope…**
- There's always a tendency … to take the whole project on
- **Don't be responsible for changing everything.**

Topher White: (8:50)

- **The other thing is that, we like to try a lot of different things.**
- **If the end of the day instead of coming up with 1 or 2, if you come up with a handful of ones you want us to try, that's even more fun and more cool.**
- Especially because it becomes a way that people can continue this without us and continue to test things without us.

Gary Paddick: (9:20)

- (Explaining the screening process as a communication tool.)
- Ask them about being part of each screening process

Topher White:

- Absolutely.
- Being part of that process would actually be kind of cool because there would be a lot to learn from you on how to take… we get into the situation sometimes where we don't want to be hearing ideas all the time, because we want to focus on the few of them that we think are promising.
- **Having that sort of framework for how to deal with a lot of ideas that you're laying out for us is, to learn from you…**
- (have to change rooms)

Appendix 3.3: 2015-12-14: Project Overview with Topher White and Dave Grenell (Highlights) – Part 2

Interview with Topher White from RFCx

Part 2 - January 4, 2016

Note: A good portion of this conversation was spent discussing the project and its intended outcomes. When the conversation was not regarding customer needs it has been summarized in bullet points. Statements relating to customer needs are written verbatim.

All quotes by Topher White, unless otherwise noted.

Conversation Participants:

- Topher White (RFCx)
- Dave Grenell (RFCx)
- Gary Paddick (Aalto)

Recap:

1. Background info on the current state of the device was given
   a. Ex: Box is getting bigger, the installation mount, etc.
2. Device is modular. Extras include:
   a. Directional antenna
   b. Extra solar panel array (same as main device, minus the cell phone)
3. Directional antenna used when cell towers are many km away
4. Installation and setup process is not simple
   a. Requires the positioning of the directional antenna and potentially additional solar panels.
5. All installation steps (or modules) are **not** required in all locations (dir. antenna and extra solar panels)
   a. Extra steps really draw out the process
   b. Advised that, "So you don't need to focus on those, necessarily."
6. Antenna should be 4-5 ft. away from the device to avoid signal interference.
7. More love for an extending pole idea from Dave and Topher
8. Fans of simple ideas that they can immediately start playing with.
   a. "We have a budget that would allow me to … if you find something that that you think is a good model, I'll just go buy it." - Dave
9. Don't always have cell signal at the ground level (but will in Ecuador)
10. ***"Being able to do, maybe just a cell service test, over the course of an hour or two, or over a night; without necessarily considering a permanent installation; without having to climb the tree, could be a real asset."*** a totally different place in terms of reception
11. Up in the tree is, "a totally different place in terms of reception."
   a. "… if you put them on the ground you really don't have any idea about whether it's going to work up in the tree or not. "
12. Idea proposed again for a hexcopter to test signal.

13. **Would like to lighten load (gear).**
    a. Climbing gear = 90% of load.
14. Freedom (for me/the thesis) to look at any area of the process
    a. *"You're welcome to think of climbing trees and the tree climbing gear, like the big shot."*
    b. *"You're welcome to get involved in any of this stuff that you think is best."*
    c. Note: Did not sound enthused at looking at tree climbing options.
15. ***"You also don't have to necessarily … take on the entire thing"***
16. "…**…, if you're able to simplify one aspect of the project** and we **<u>don't have to climb the tree to test the cell service. That's huge. That saves us like 3 hours."</u>**
17. **Need for a sellable, scalable solution. They don't have one at the moment.**
    a. Can be pie in the sky solution.
    b. So it doesn't necessarily have to be something we can use immediately, if it's something we could put some abstract price tag on.
18. "One thing we can all agree on is that use doing the installations in every country is not a way to scale it up, and protect a lot of rainforest."
19. "…because like we said it, 20 countries have invited us. **They don't always have funding,** but if we had a way that they could mount devices that's really simple, we would be able to start **sending them devices in 2017… is the goal."**
20. **"… currently they would have to climb tree and as we discussed that makes some of our partner quite nervous"**
21. **"The simpler the better, if it's imaginable. It really does <u>help our communication</u>."**
22. Confirmation of project deliverable being a concept(s)
    a. "Yeah. For sure, especially if we're able to learn from you the way in which you go through and eliminate certain concepts and stick to others, stuff like that. Participate in that for sure."
23. Preference for two segment tracks.
    a. Ultimately scalable and quickly testable/implementable
    b. "It would be great if in terms of conclusions to the project if you were able to say, "Okay, there has to be 1 or 2 solutions that are the best." We want those to be the ones that we can test in the next pilot project or two, but also being able to highlight the ones that might …(cut out)… but might takes some investment that's useful for us on the communication side."
24. Priority between the two is time to implementation:
    a. "Because it's a concept piece… concept piece is never quite useful until you test it, so…"
    b. "Let's focus on things that we would be able to test without huge investments."
25. **<u>"… less automate, more obvious is a probably a good principle to stick with."</u>**

Topher White:

- Continue from previous conversation/thought on idea fatigue.
- Asks about what I know of the device and looks to explain.
- Wants to go over the device and its mount.

- Most important piece you can take into account – (the mounting bracket)
    - (Sends 3D model of it)
    - (We go through the mount, its orientation, and how the device connects with it)
- The device "box" is getting bigger. (The box that holds the cell phone and components)
- Usually using 2 screws in the center of the mount (out of 3 holes) to attach the device to the tree.

Topher White: (3:40)

- That's the current process for installing it.
- **That's hard to imagine doing at distance of any more than a few feet.**
- There's no reason we have to use the screws.
- Just to give you an idea of what we do now.

Topher White: (4:50)

- **Then sometimes we will attach extra solar panels** if we feel there's not enough sunlight in the area to really make it work.
- Each one (additional solar panel array) uses a mount as well.
- We'll end up having to connect those solar panels to this device.
- There will be a double set of solar panels, but only one will have a box inside of it (box holding the cell phone/device).
- (Believes there is a video of the double solar panels. Attempt was made to send, but it was never received.)
- (**There's a frame that holds the solar panels that snaps into the mount. It's this frame that holds the box.)**
- You slide the box into the frame. That frame then holds the solar panels.
- Then you take that frame and mount it. Put into the mounting bracket and the mounting bracket attaches to the tree.
- There doesn't need to be a box in the frame to hold the solar panels.

Topher White: (7:40)

- Attached to the box.

Topher White: (8:30)

- Directional antenna, they look like big antennas.
- Point them in the (*static*) direction.
- **That will then be connected via cable to the device.**
- Then you'll have to positon the antenna to pick up the cell signal.
- **It's coming from a cell tower which is often many km away.**
- **Then there's the process of actually making sure everything is pointing …**
- **You do that generally by connecting to the device or connecting the antenna to another phone, and finding the best signal based on that.**
- <u>**That's pretty much it, but you can see that it's not nearly as simple or automatic…**</u>

Topher White: (9:27)

- Depending on where we are not all of those things are necessary.
- In the best case scenario, we’re in a place where we’re 10 … (cut out)... or so from a cell tower.
- Which a lot of places we look to install are, so it doesn’t need an extra antenna.
- If you’re able to find a place on the tree where there’s pretty good sunlight from at least one direction, you may not need an extra set of solar panels.
- **Those two extra steps that really draw out the process and make it much more manually, potentially may not always be necessary.**
- **So you don’t need to focus on those, necessarily.**
- **But at least over the next few deployments we are going to putting a focus on trying to do those in most cases, just to play it safe.**

Gary Paddick: (10:11)

- How far away from the initial installation point are the extra modular parts of the system (antenna and solar panels) installed in the tree?

Topher White:

- Depends on where they can be attached to the tree.
- Also helps to have the antenna farther away from the device (can be cell signal interference)
- **4 – 5 ft. away from the device.**
- **All the extra altitude you get with the antenna is great.**
- The positioning of the antenna is often the most difficult and required you to do it manually up in the tree.
- Since that’s included in installations that are much farther away from the cell phone networks, which the last two we’ve done have been**. It may not be something you’ll find it worth your time to focus on.**
- I can’t at least think of any way you could do that from afar. At least from the beginning.

Gary Paddick: (11:40)

- (Explain about trying to find the greatest pain point, that could be the most useful to simplify)

Dave Grenell: (12:06)

- Idea we were talking about that I thought was worthy of more exploration…
- **The kind of extended aluminum pole.**
- **Something that’s so simple we could immediately start playing with something like that.**
- **You shoot something into a tree, like a bolt. That you can hang something on with a … aluminum extendable pole and at least for testing**.
- Not necessarily for an installation, but that’s a great fast way to put up a temp device.

Topher White: (12:50)

- Ah, okay.
- **Especially in Ecuador, we have already confirmed that in all the places in this particular reserve where we're going to be testing it there is cell phone service even at the ground level, which is not the case in any of the other places before.**
- This is a pretty ideal place for us to be working on something like you just described.

Topher White: (13:10)

- When Dave and I were first testing in Cameroon, we didn't want to necessarily climb a tree to do signal testing.
- **It wasn't until after that, that we realized that if you put them on the ground you really don't have any idea about whether it's going to work up in the tree or not.**
- **It's a totally different place in terms of reception.**
- ***Being able to do, maybe just a cell service test, over the course of an hour or two, or over a night; without necessarily considering a permanent installation; without having to climb the tree, could be a real asset.***

Dave Grenell: (14:00)

- **One of the ideas should be putting a phone up on a hexcopter.**
- Those are 2 really good ideas we could start playing with.

Dave Grenell: (15:00)

- Prioritizing things on the list, there are a number of things we could potentially implement soon.
- **Like the aluminum pole is a great, simple idea.**
- We have a budget that would allow me to … if you find something that that you think is a good model, I'll just go buy it.

Gary Paddick: (15:40)

- (Tell them I'll send them a list of some short term solutions that could be tried out. – reaction = excitement)
- (Mention the big shot mod – reaction = lose excitement)

Topher White: (16:20)

- ***Not trying to carry quite as much stuff every time we go out to do it. (In response to Big Shot mod)***
- ***Climbing trees requires a lot of gear… and lightening that load….***

Gary Paddick:

- You're talking about the actual on your back load to get the tree or site?

Topher White:

- **Yeah. Basically carrying the climbing gear makes up 90% of it.**
- **We also take in the tools, and the device and all the rest of that stuff.**

- **<u>Anytime we're able to make one thing we're bringing along when it comes to climbing ….kind of a double purpose certainly will lighten the load and make it a little bit more practical to do this.</u>**
- *You're welcome to think of climbing trees and the tree climbing gear, like the big shot.*
- *You're welcome to get involved in any of this stuff that you think is best.*
- ***You also don't have to necessarily … take on the entire thing***
- Similar to the aluminum pole idea **…, if you're able to simplify one aspect of the project** and we **<u>don't have to climb the tree to test the cell service. That's huge. That saves us like 3 hours.</u>**
- Because often times we climb a tree 2 or 3 times, just for a simple device… (cut out)… and that obviously takes more than a day for each of those.
- Although we have that time for the pilot project.
- It's not something you want …. (cut out)… 60

Dave Grenell: (17:52)

- Gary and I also discussed, in terms of the theoretical ends of the project. One of our problems is people want to go to scale and so simplicity of even being able to talk about a solution that's scalable…. there's stuff we could do immediately in Ecuador … but coming up within your idea the things that we can at least say this is what we would do if we could, means we could actually potentially get funding
  - Topher White: Yeah
- Because people ask, "Oh how would you do this if you want to protect in 15 countries? "
- There's currently not a great answer

Topher White: (18:65)

- **So it doesn't necessarily have to be something we can use immediately, if it's something we could put some abstract price tag on.**

Dave Grenell:

- Right.
- **Or it seems simple enough that someone would say, "Oh yeah, that makes sense."**
- **One thing we can all agree on is that use doing the installations in every country is not a way to scale it up, and protect a lot of rainforest.**
- **… making it less expert….**

Dave Grenell: (19:00)

- **…because like we said it, 20 countries have invited us. They don't always have funding, but if we had a way that they could mount devices that's really simple, we would be able to start sending them devices in 2017… is the goal.**
- **… currently they would have to climb tree and as we discussed that makes some of our partner quite nervous**
- **… and training issues…blah blah blah.**

Topher White: (20:32)

- **The simpler the better, if it's imaginable. It really does help our communication.**
- On the outside our idea is super simple, which is putting phones up in trees and they listen to the sounds of the rainforest
- On the actual application side of things, it turns out to be that plus 12 or 15 other steps that tend to take a lot of time and be pretty complicated and currently expensive, so…
- But the fact that it is a simple idea that people can get really helped us sort of get it out there.
- **The simpler the installation seems, in line with the simplicity of the idea certainly will help us.**
- **Which is why I like the pole idea**…. it's pretty cool.

Gary Paddick: (21:20)

- Just to cap this part off, we're all happy with the end goal… of more of a concepts, than actual detail design?

Topher White:

- **Yeah. For sure, especially if we're able to learn from you the way in which you go through and eliminate certain concepts and stick to others, stuff like that.**
- **Participate in that for sure.**

Gary Paddick: (21:50)

- When I start going through the evaluation I want you guys to take a look at it and comment on what the criteria and how we're rating.
- Make sure all of our goals are in line.
- If you want something that's more … I can add a criteria for development time…. that way we can look at the more realistic solutions.

Topher White: (22:28)

- It would be great if there was almost two tracks for that.
- If it was to be ultimately scalable, then the amount of time it takes to develop the solution is less critical. We wouldn't want to eliminate that idea simply because it might take some focus to develop.
- But also take into account that that's not the type of thing we're going to be able to test in the near future.
- **It would be great if in terms of conclusions to the project if you were able to say, "Okay, there has to be 1 or 2 solutions that are the best." We want those to be the ones that we can test in the next pilot project or two, but also being able to highlight the ones that might …(cut out)… but might takes some investment that's useful for us on the <u>communication side</u>.**

Gary Paddick: (23:24)

- If you had to pick between the two, what would be your higher priority?

Topher White:

- Between the two?
- Between time of development vs imminent testability.
- **Because it's a concept piece… concept piece is never quite useful until you test it, so…**
- **Let's focus on things that we would be able to test without huge investments.**
- But that doesn't mean… if the investment is like buy a drill, that's not a… that's like a purchase investment, so that doesn't count as a huge investment.

Gary Paddick: (24:20)

- Ah no, in my mind there would be a separate criteria for overall cost of the solution versus; another criteria would be how long would it take the development investment. The time and resources.
- Topher White: Okay
- (Speak about development time of complicated device)

Topher White: (24:57)

- **It's also likely to be the type of thing that we have to troubleshoot and solve, and it becomes a whole other thing we have to maintain, so …**
- **… less automate, more obvious is a probably a good principle to stick with.**

Gary Paddick: (25:40)

- Last thing, the climbing method that you guys are using…the actual climbing technique.

Topher White: (26:10)

- The way it works, not sure what video you saw, but…
- We use the big shot to shoot a line up into a tree.
- That usually takes the longest, is finding the right branch.
- Sometimes can take up to an hour, if it's a high branch or something.
- That line shoots a thin line over the tree.
- We use that to pull up a thick rope that we can actually climb on.
- That 1 rope coming down.
- Sometimes depending on how high up the branch is, sometimes you need to deal with the fact that there are many other branches in the way. Which slows things down.
- Then basically you hook up a harness to that rope and then some foot jumars, and you climb up that single rope to the branch.

Gary Paddick: (27:04)

- And that's where I'm looking more info. For the clipping in and climbing up, I'm looking for more info on what you're doing there.

Topher White:

- Great. I just shot some video of my explaining this technique to the Tembe tribe who are our partners down in Brazil. I don't think it's very interesting video, but I'll send it to you.

Gary Paddick:

- That sounds great!

Appendix 4

Concept Catalogue

A list of concepts generated throughout the project. Concepts listed in the catalogue were decomposed into their solution principles and placed in the concept classification tree. The list is a truncated version of the original list, with non-critical columns removed. The electronic version indicates the concept classification tree that the decomposed solution principle from a concept was placed. Descriptions are absent from concepts whose title are self explanatory or whose title is a description.

The column title “Dwg. Stat.” indicates drawing status.

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
1	2015-11-01	None	Purchase a commercial power ascender	A number of commercial power ascenders are on the market for pulling an operator up a climbing line. Some include seats for comfort, and man can double as a winch. Available in gas, batter, and electric powered models. Used by arborists, sportsmen, and tower inspectors.
2	2015-09-24	Light sketch	Spool reel in - ”Auto climber / fishing reel”	Install mount in tree, pull up device with fishing line (either from ground or spring powered spool in mount), clip device into mount
3	2015-09-24	Light sketch	Teeth clamp	Encircle branch/tree trunk with large ”teeth clamp”, use a bike wire trigger to lock on location
4	2015-09-24	Light sketch	Spider clamp	Pre-tensioned clamp arms are held back. When inner surface of clamp is pushed against the tree trunk/branch, a trigger releases the tensioned arms, and they snap around the tree trunk/branch.
5	2015-09-25	Light sketch	Large squeeze hand clamp	Modify a standard hand clamp, so that you can lock it in the open position. Then use either a pressure trigger (spider clamp) or a pull trigger (bike break) to release so that the clamp closes.
6	2015-11-14	None	Hexcopter bring up/tie throwline	
7	2015-11-14	None	Underside of branch install, pull up device on throw line, with auto clamp	Place throwline, pull up the device by hand, have auto clamp latch onto underside of tree branch, have solar panels flipped so still pointing upwards

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
8	2015-11-14	None	Remote method to unlock pulley rope - electromagnet	
9	2015-11-14	None	Pull up device on throwline, rope around tree attach	Use a pulley point to raise the device, and have a loop of rope already around the tree for attachment
10	2015-11-14	None	Line Climber - Modify gris-gris	
11	2015-11-14	None	Self-locking carabiner as auto-clamp	
12	2015-11-14	None	Carabiner with electromagnet	To pull back the carabiner to allow for retrieval
13	2015-11-27	Very light sketch	Rope mount, tied by drone	Drone flies up and builds a mounting point from rope stored in a spool on the drone. Multiple wraps.
14	2016-01-21	Light sketch	Low elevation, telescopic stick clip, with tight enable rope mount.	A lightweight telescopic pole for low installs (7m) that would raise a rope mount, based on friction hitches, set at the base of the tree and tightened at the installation height. Device is clipped into a loop in the rope mount by either being pulled up with a fishing line or attached in a stick clip manner.
15	2016-01-21	Light sketch	Long pole end support clamp, with tightening loop of rope to provide a stable installation platform for a fastening method.	Use a long pole variant, end supported by a circular metal guide, with a pack up safety rope noose and rollers between it and the tree trunk. The rope noose is tightened at height to secure the pole end, to allow a stable platform to operate a fastening method (impact screw, nail gun, etc.).
16	2016-02-02	Very light sketch	Powerlock cable tensioner	Modify powerlock cable tensioner used in hunting stand hanging.

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
17	2016-02-02	Very light sketch	Detachable collar mount that digs into the tree trunk.	Inspired by Atlas military end of pole hook attachment (for rapid access), a metal collar end support with small hooks on the inside is dug into the tree trunk and detached from the pole. The collar can be a full mount (pulley or direct device).
18	2016-02-02	None	Detachable hook (pulley point/clip point)	Inspired by Atlas military end of pole hook attachment (for rapid access), a large hook is dug into the tree trunk and detached from the pole. The hook can be a pulley point or hanging point, or a direct device install.
19	2016-02-02	Good sketch (some work needed)	Rolatube pole with ground support	A mostly developed raising concept. Use a ground mount support tube for connecting of multiple rolatubes as a segment pole.
20	2016-02-03	Light sketch	Tripod with crank leg	A tripod with adjustable legs, one or all of which have lengths controlled by a hand-crank. Used to support a long pole. Allows for pushing the end of the pole against the tree trunk, by lengthening the leg farthest from tree trunk.
21	2016-02-03	Light sketch	Gorilla-pod support - support device while raising	Gorilla pod (gooseneck tubes) for support and reduce friction/snags between end of pole and the tree trunk.
22	2016-02-04	good sketch	Sectional pole tripod, with pulley cap/lifting shoe	From YouTube video. Great method for installing communication sectional masts.
23	2016-02-04	good sketch	Sectional pole with direct drive crank - worm gear/rack and pinion	Standard direct drive crank to extend pole. Utilized in military (windup poles) and DJ equipment stands
24	2016-02-04	good sketch	Sectional pole tripod, with direct drive crank - friction rollers	Inspired by hot wheels race car tracks, multiple rollers use friction to hold and apply force to the exterior of the pole segments

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
25	2016-02-04	good sketch	Sectional pole tripod, with pneumatic lift	Uses an accordion style, inflatable position to push up on the bottom of the last segment. Guides can be used to ensure stability during inflation.
26	2016-02-04	None	Sectional pole tripod, with roleatube lift	Uses a roleatube to push up on the bottom of the last segment. Guides can be used to ensure stability during inflation.
27	2016-02-04	good sketch	Sectional pole tripod, with foot lever to lift	Uses foot lever to push up on the bottom of the last segment. Guides can be used to ensure stability during inflation.
28	2016-02-08	Really good sketch	Sectional pole tripod replacement, with pulley cap/lifting shoe - Direct Attach	Attach a guide/support directly to the tree trunk, with a hunting climbing stick style v-bracket and nylon strapping. Can be used with telescopic or segment pole. If segment pole can still use lifting shoe pulley system.
29	2016-02-08	Rough Sketch	Sectional pole tripod replacement, with pulley cap/lifting shoe - Webbing attach	Collar/support suspended in air by multiple lines connected to 3-6 trees.
30	2016-02-10	Rough Sketch	Direct attach tree mount, with lifting shoe pulley, with pulley point attached to 2nd tree trunk	
31	2016-02-10	Good Sketch	Horizontal segment pole raised with tree trunk base as pulley point	Based off Comrod 10m segment mast
32	2016-02-10	Good Sketch	Lifting shoe variants	
33	2016-02-08	Good Sketch	Guy wire supports for segment pole	
34	2016-02-08	Good Sketch	Mid-level supports for segment pole	
35	2016-02-11	Good Sketch	Guy wire supports for telescopic, windup pole	
36	2016-02-11	Good Sketch	Guy wire supports for telescopic, windup pole	

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
37	2016-02-11	Good Sketch	Locking pin for pulley connection to segment pole	
38	2016-02-11	Good Sketch	Telescopic pole + direct attach tree mount + pulley to extend pole	
39	2016-02-11	Good Sketch	Windup pole with direct attach tree mount	
40	2016-02-11	Good Sketch	Windup pole with hinged baseplate and tree pulley	Pulley is to control angle between pole and horizontal
41	2016-02-11	Good Sketch	Baseplate variants	
42	2016-02-11	Good Sketch	Direct attach tree mount ”rocker” variant	
43	2016-02-16	Rough Sketch	Spring Powered Nailer	Quick concept for stored energy nailer using a pre-loaded spring.
44	2016-02-17	Rough Sketch	End of Pole Support - Ground crank to tighten noose at height to provide a stable installation platform for a ”fastening mechanism”	For end support of long pole, not attaching the actual device
45	2016-02-17	Rough Sketch	End of Pole Support - Gorilla-pod end support that completely encircles the tree trunk	For end support of long pole, not attaching the actual device
46	2016-02-17	Very Rough Sketch	Gripper Claw- Snap out preloaded arms	For end support of long pole, not attaching the actual device
47	2016-02-17	Rough Sketch	Gripper Claw - Fully encircle at base, push up and tighten. (For end support)	For end support of long pole, not attaching the actual device. Multiple tightening methods included in concept map.
48	2016-02-17	None	Gripper Claw - Classic robotic arm with electric motors	For end support of long pole, not attaching the actual device. Variations included in concept map.
49	2016-02-17	Rough Sketch	Autonomous drone install, with drone gripper arm	Gripper arm attaches the drone to the tree
50	2016-02-17	Very Rough Sketch	Drone Gripper Claw - Similar concepts to end of pole gripper claw	For end support of drone. Variants included in concept map

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
51	2016-02-17	Rough Sketch	Drone Gripper Claw - Actuator arm	For end support of drone. Variants included in concept map
52	2016-02-17	Very Rough Sketch	Drone Attachment - Spring powered nailer with backboard	
53	2016-02-17	None	End of Pole Device Attachment - Attaching device by tightening a loop of material.	Variants for tightening the loop included in concept map.
54	2016-02-17	None	End of Pole Support - Secure end of pole by temporarily tightening a loop of material.	Variants for tightening/loosening the loop included in concept map.
55	2016-02-17	None	Bio-degradable rope mount for temporary low level installs (testing phase)	Use a biodegradable rope to fashion a mounting point for the test device. Would then retrieve the device, but could leave the mount on the tree.
56	2016-02-18	Good Sketch	Birdhouse wire for attachment	Inspired by story of Finnish childhood
57	2016-02-18	None	Backing board concepts - mount	
58	2016-02-18	None	Long Pole + Birdhouse wire	
59	2016-02-18	None	Long Pole - Backup line for device safety	
60	2016-02-18	Good Sketch	Long Segment Pole + Rocker ground support mount + birdhouse wire	
61	2016-02-18	None	Long Segment Pole + hinge baseplate + birdhouse wire	
62	2016-02-18	Good Sketch	Rocker tree ground support with locking positions	Modification of the ”Rocker” long pole ground support that attaches directly to the tree trunk
63	2016-02-18	Rough Sketch	Telescopic pole + Birdhouse wire + hinge baseplate with pole shoe	
64	2016-02-18	Rough Sketch	Telescopic pole + manual end support + birdhouse wire + pole support gorilla pods and tether	

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
65	2016-02-18	Good Sketch	Squeeze clamp + bike cable	
66	2016-02-18	Decent Sketch	Pole end support: Gorilla pods with tether + v-bracket	
67	2016-02-18	None	Spool reel in - Mount attached	A spool to store line is built into the mount. Once mount is installed, the spool is operated to pull up the device and clip it into the mount
68	2016-02-19	Good sketch	Spool reel in - Device attached	A spool to store line is attached to the device. Once mount is installed, the spool is operated to pull up the device and clip it into the mount
69	2016-02-18	None	Tree Stepp for low level installs - climbing method	Use the Tree Stepp as intended to install test devices in the 20 ft. range.
70	2016-02-18	None	Tree Stepp - as a clip/pulley point	Use Tree Stepp design as a simple mount
71	2016-02-19	Good sketch	Manual pull up the device with the mount as the pulley point; pulley line secured to tree trunk to secure device	First install mount. Use mount as pulley point for the line. Pull up device, sits in mount. Tie end of line around tree trunk base to secure device. Untie to retrieve device.
72	2016-02-23	Light sketch	Use/modify product ”EZ Hang Hook” as a pulley/hanging point.	Polyester webbing, with a metal triangle hook joining the ends. A ratchet strap for tightening
73	2016-02-23	Light sketch	Rope mount based on hunting gear hanger	Rope attached to metal hook, other end with a friction knot, to allow easy pull tightening (no ratchet strap)
74	2016-02-23	Light sketch	Rope mount with center placed know	For easier tightening of mount
75	2016-02-23	None	Wire stripper inspired tail tensioner and cutter	For pulling the tail of a loop. Tighten end, and cut - wire stripper motion with a full cut
76	2016-02-23	None	Wire stripper inspired tail tensioner	For pulling the tail of a loop. Tighten the end, then disconnect - pull rope towards device motion
77	2016-02-23	Light sketch	Mount attached with loop end locked with a vertical rope cam	Tighten the rope attachment mount - downward pull to tighten, with the line locked in a cam cleat

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
78	2016-02-23	None	Mount attached with loop end locked with a vertical rope clam	Tighten the rope attachment mount - downward pull to tighten, with the line locked in a clam cleat
79	2016-02-23	None	Convert mini climbing sticks into hanger/pulley point mount.	
80	2016-02-23	None	Convert/use tree handles as a hanger/pulley point mount.	
81	2016-02-23	Very rough sketch	Climbing stick inspired attachment methods for mounts	Versa button loop, rope modification, webbing and ratchet strap.
82	2016-02-23	Rough Sketch	Mount attached with simple rope support and knob, with a long pole connector	Lone wolf inspired versa button, with rope modification Use of friction hitches to secure a rope attachment. Designed with a long pole connection in mind, but not mandatory
83	2016-02-23	Rough Sketch	Mount Support with Vertical Webbing Buckle	Allows downward force to tighten webbing. Uses versa button (lone wolf). Designed with a long pole connection in mind, but not mandatory.
84	2016-02-23	None	Detach entire mount assembly from tree with the use of a long pole.	Reconnection the long pole into the bottom of the mount allows for the device to be secured and supported for descent
85	2016-02-23	None	Easy reconnect to mount gives known distance for operation of detachment method of mount	Interaction of pole end devices designed to operate on known location of moment to detach it from the tree. (ex: Cutting shears for rope mount, locking strap for webbing, etc.)
86	2016-02-23	Rough Sketch	Rope Sleeve Connector	Connector between the length of material (rope/cord) used to attach the mount to the tree, and a 2nd pull line that goes from the attachment point to the ground.
87	2016-02-23	None	Modified come-a-long	Modify a come-a-long that can be operated and disengaged remotely. Use to tighten webbing for device/mount attachment

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
88	2016-02-23	None	Lone wolf V-bracket to be used as end of pole support and/or device installation mount bracket	Depending if the v-bracket is for attachment or traversing the tree trunk it either can keep the original design or by made smooth (reduce friction)
89	2016-02-24	Rough Sketch	Tapered cone pole/mount connector	A tapered cone shaped pole end connects with the mount by passing through a hollow tube that is part of the mount construction.
90	2016-02-24	Rough Sketch	Sleeve pole/mount connector with mount shelf/lip	Once pole/mount sleeve connector is through the sleeve, the mount sits on a shelf that is part of the pole connector. This allows the mount to stay in place through gravity.
91	2016-02-24	Good	Sleeve pole/mount connector with mount shelf/lip + birdhouse wire (attach/retrieve) + v-bracket on mount.	
92	2016-02-24	None	Sleeve pole/mount connector with press fit mount + birdhouse wire (attach/retrieve) + wooden backboard	
93	2016-02-24	Decent Sketch	Custom make: Tree Stand inspired mount + Cam Cleat locking rope attachment + end of pole retrieval	Custom made mount. For all tying based attachment methods. Includes bark teeth and pole sleeve connector
94	2016-02-24	Decent Sketch	Modify: Tree Stand inspired mount + Cam Cleat locking rope attachment + end of pole retrieval	Custom made mount. For all tying based attachment methods. Includes bark teeth and pole sleeve connector
95	2016-02-24	Decent Sketch	Box mount + internal full sleeve pole/mount connector + Bottom funnel for guiding reconnect	Fully encased pole (connector) sleeve to give full front/backboard mount. Useful for friction area for mount to tree trunk surface

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
96	2016-02-24	Very Rough Sketch	Large receiver flange inside of mount + small pole sleeve + press fit mount onto pole connector	Turn whole back of mount into a receiver flange, with only a short connection sleeve. This way, when attempting to reconnect all the operator needs to do is aim for the entire bottom of the mount.
97	2016-02-24	Very Rough Sketch	Pole/mount connector support lip/shelf with front shield	
98	2016-02-24	Very Rough Sketch	Wire attachment tightening with wire fence tensioner	Utilizes a rotational force to contract a loop of wire
99	2016-02-24	None	Birdhouse wire + In-line wire tensioner + Pole Mount + Long Pole	
100	2016-02-24	None	Modify a Nite Ize ”Camjam” for a line locking and/or pulley/hook mount	A cheap product that provides a self locking cam with a carabiner clip. For use with cord/rope
101	2016-02-24	None	Shelf (lip) pole connector + Square tube mount + Birdhouse wire attachment (with optional in-line wire tensioner)	
102	2016-02-25	None	Rope attachment by: tightening line + locking cam cleats + tail cutter	Pull to tighten rope from ground and cut tail with garden pole shears inspired cutter
103	2016-02-25	Very Rough Sketch	Double ground pull activated torque wrench	Two line system that, with each line pulling the torque wrench in the opposite direction
104	2016-02-25	Very Rough Sketch	Single ground pull activated torque wrench	Single pull line system
105	2016-02-25	Very Rough Sketch	Tighten loop of material with direct spool knob	Tighten loop by taking in the slack in a pre-tied loop.

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
106	2016-02-25	Rough Sketch	Dual spools with ground crank (closed loop) to proved rotational force at height	Rotational force is applied at height by a large closed loop of material (cable, cord, etc.) contained in spools (to allows for loop size variability). Two of the spools are attached to a ground crank, while the other two are at the installation height
107	2016-02-25	Rough Sketch	Dual spools with ground crank + long pool	Loop lines run through center of hollow long pole
108	2016-02-25	**Very Good sketch**	**Square tube mount/sleeve + pole/mount connect shelf + v-bracket + pull tighten rope attachment + friction hitch lock + cut tail**	
109	2016-02-25	Rough Sketch	Loop support - gorilla pods under the loop	
110	2016-03-07	Rough Sketch	Squeeze clamp grip inside pole connector to pull attachment tail	Bike brake cable triggered
111	2016-03-07	Rough Sketch	Line Locking Mechanism: Two U-bolts in line with a sliding stopper knot in between	
112	2016-03-07	Rough Sketch	Double rope friction hitch tightening line	Similar to standard tightening line, but with the rope doubled up and tucked through a single U-bolt
113	2016-03-07	Rough Sketch	Simple double static loop setup for mount	To increase attachment friction
114	2016-03-08	None	Slip knot as pull line to attachment line connector for tightening	

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
115	**2016-03-09**	**Good Sketch**	**Bachmann hitch to secure tightened loop for mount attachment**	Use of a Bachmann hitch to tighten and lock the tail of a loop of material around the tree trunk. A Bachmann is tied around line and a U shaped handle bracket on side of the mount. Pulling on the tail of the loop will tighten the line through the Bachmann, which wont allow it to loosen.
116	2016-03-09	None	Tighten line fail safe - U-bolt and keeper knot	Would result in a loose loop, so device/mount would fall short distance, but tests on static loops show that it should catch fairly quickly.
117	2016-03-09	None	Tighten line fail safe - friction melt cord	
118	2016-03-09	None	Single loop hollow braided cord	Hollow cord flattens under tension, which would increase the surface area and therefore holding friction
119	2016-03-09	None	Distel hitch for line attachment	
120	**2016-03-09**	**None**	**Line climber pusher + distel hitch**	**Device is attached to a pre-set line with a distel hitch. A line climber then pushed the device up the pre-set line. Once all the way up, the line climber comes back down and the device remains on the distel hitch**
121	**2016-03-09**	**None**	**Bachmann hitch + double tighten line attachment**	**Provides easy attachment point for tightening the loop without the need for tail cutting**
122	2016-05-06	Rough Sketch	Tie line around tree trunk at height - Ant Robot	An ant or worm like small robot is able to walk around the circumference of the tree trunk with a pull line. A pre-twisted line or wire could be strong enough to hold the robot up against gravity. Then the robot only needs to provide the force to move around the tree trunk. Wire may be stiff enough to hold the robot as is.

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
123	2016-05-06	Rough Sketch	Tie line around tree trunk at height - Wire pusher	A wire preloaded in such a manner that it wants to naturally move clockwise around the tree trunk when pushed outwards from its spool
124	2016-05-06	Rough Sketch	Tie line around tree trunk at height - Unfolded arm	Series of arms that unfold around the tree trunk, bringing the wire with it.
125	2016-02-12	None	Long Pole - Military communication mast; telescopic;	Single operator, telescopic pole with a high end load capacity.
126	2016-02-12	None	Long Pole - Military expedition sectional masts	Single operator, tripod mounted mast, with top winch system, backpack carry able.
127	2016-02-12	None	Long Pole - Military, vehicle mounted telescopic pole	
128	2016-01-22	None	Long Pole - Telescopic; Window washing	Aluminum, carbon fiber (various modulus), fiberglass
129	2016-01-22	None	Long Pole - Telescopic + segment combo; Window washing	
130	2016-01-22	None	Long Pole - Sectional; arborist	50 ft. arborist designed segment pole
131	2016-01-22	None	Long Pole - Telescopic, fiberglass, for antennas	Extreme telescopic pole, 60 ft. (18 m) lots of flex, would need to be able to extend straight up (not extend and then put against tree)
132	2016-02-16	None	Powder fastening tools	Use explosive powder to drive high velocity fasteners (studs), includes models activated by a hammer hit.
133	2016-02-16	None	Gas fastening tools	Use gas mixed with air to drive high velocity fasteners (studs)
134	2016-02-19	None	Hammer tacker/stapler attachment	
135	2016-03-02	None	Yankee Push Drill for at height attachment	
136	2016-02-12	None	Ribbon mast to raise the device	High end load capacity, small foot print, high weight
137	2016-02-03	None	DJ Mobile stand, with crank up masts	Crank up portable mast, high top load
138	2016-02-03	None	18m Telescopic crank-up aluminum mast	Hand crank, telescopic mast, tripod supported, 50 kg top load

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
139	2016-02-23	None	Look to tree hunting accessory mounts for tree mount needs	Most have simple arms off a center square tube. Ratchet strap and nylon webbing often used to secure the mount.
140	2015-12-11	None	Set line in tree with rescue/military grade pneumatic launchers	Compact, light weight, high range, can be equipped with grappling hook.
141	2015-12-11	None	Set line in tree with DIY pneumatic launchers	Compact, light weight, high range, cheap. Made from PVC pipe.
142	2015-12-11	None	Set line in tree with arborist pneumatic launcher	Compact, light weight, good range, cheap.
143	**2015-12-11**	**None**	**Military rapid access pneumatic pole**	**50 ft. for 25 lbs.**
144	2016-01-27	None	Modify/utilize military rapid access equipment	Includes telescopic poles, grappling hooks, roll-out composite pole, fold out ladders.
145	**2015-11-24**	**Good sketch**	**False Crotch + Riggers Winch + Electric Drill**	**A standard sail boat riggers winch is strapped to the tree trunk base. An arborist line is setup in a false crotch, providing a pulley point for a 2nd line. The 2nd line goes through the winch, with the other end attached to the climbers safety harness. The riggers winch can then be operated manually or with an electric drill.**
146	2016-01-21	None	Pull cord operated pruning shears that operate at the end of long poles (21 ft.).	A commercial example and inspiration for cord pull operated tools.
147	2015-11-26	None	Line placement - Big shot trigger modification	A simple DIY modification to the standard Big Shot (currently used by RFCx). Uses a pulley system to hold the sling back, while an archery trigger is used for the release
148	2015-11-26	None	Utilize updated climbing techniques and equipment	Includes secured foot lock, frog walker system, rope wrench system, etc.

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
149	2016-01-22	NA	Hire professional arborists for a few weeks of intense installation (not testing)	
150	2016-01-22	NA	Workforce from volunteer tourists	
152	2016-05-30	None	Double static loop of wire + through U-bolt + pre-twist wire to keep off of tree trunk + birdhouse wire attachment	
153	2016-05-31	None	Independent Line Climber + Tightened Loop of Material	Device is raised on a line climber and arborist set line. Device is not directly connected to the line. A loose loop of material is set around the tree trunk at the base and tightened by the line climber at the installation heights, pulling the device tight to the tree trunk.
154	2016-06-04	None	Dynamic loop + electric motor as part of mount + solar panels	Use of an electric motor as part of the device mount to tighten and adjust the slack in the attachment loop, remotely. Device hangs on a loop with some slack in it (similar to birdhouse wire concept). After a set period of time the electric motor is activated remotely to let out some more slack to prevent tree strangulation
155	2016-06-04	None	Tree strangulation prevention through a ratchet and prawl lock and a timer	Ratchet and prawl setup to a timer that activates a switch to release a set number of steps in the ratchet to let out slack in the loop of material. This is to prevent tree strangulation remotely, without operator input.
156	2016-06-04	None	Spring(s) placed between the back of the device mount and the tree trunk to help prevent tree strangulation	Mainly used for dynamic loops (not needed for static). Allows for a secure tie, while providing growing room for the tree.

Table 4.1: Concept Catalogue

No.	Date	Dwg. Stat.	Concept	Description
157	2016-06-04	None	Spring between mount and tree trunk with a force gauge.	Force gauge provides a reading of compression in the spring(s). This give input into when an attachment loop needs to be loosened to prevent tree strangulation. Could be used as a reading, or as an auto-trigger to provide slack.

Appendix 5

Field Tests

Appendix 5.1: Tree Cord/Webbing Tests 1

Synopsis:

Quick and dirty initial tests to examine and develop a feel for how static cord and nylon webbing interacts with a tree trunk. Different amounts of slack and configurations were explored with a hanging weight. Tests were conducted on Feb. 24, 2016.

Tests showed that nylon webbing and static cord can be used to secure the weight of the RFCX device (~3.7 lbs) directly to a tree trunk, along with the weight of a full grown man (~134 lbs). This is true even when the cord/webbing diameter is noticeably larger than the diameter of the tree trunk.

Further testing is to be conducted.

Questions:

1. How tight is it required to have the cord/webbing around the tree trunk in order for the weight to be secured?
2. How does the cord/webbing interact with the tree trunk and tree bark?
3. Is a tightening loop superior to a constant loop?
4. Mimic installation methods of having the device (weight) pushed up on the end of a stick. How would you make the cord/webbing attach to the tree trunk?

Results Summary:

Both the static cord (9mm) and the nylon webbing held both the 3.7 lbs weight and the tester's full body weight (~136 lbs) without any slippage of the cord/webbing. Tests were conducted with the cord/webbing attached directly to the tree trunk (not supported by any branches).

Both static cord and webbing was gripped by the tree trunk. (Not the tree type had particularly rough and segmented bark. Lots of areas for purchase). The grip was such that clearance between the cord/webbing and tree trunk would be required to raise the rope up the tree trunk (if pre-tied around the tree trunk).

There was no observed benefit to having a tightening loop over a static loop. The weight did not seem sufficient to self-tighten the loop (to tighten the tester would have to pull the loop tight, it would only tighten marginally under own weight).

Note that the cord used did not allow for an excess of slack due to length of rope.

For mimicking installation process it was found that having the device pulled away from the tree trunk (so that the back of the rope was tight against the tree trunk on the opposite side from the device) would prevent the cord from slipping downwards once the weight was dropped.

When the weight was tight against the tree, and the cord on the backside was loose, the cord would slip down until the cord made contact with the tree trunk. At that point the cord would grip the tree trunk and the weight would be secure.

Webbing available at the time of the initial testing was not long enough for significant slack testing. No vertical slippage was observed.

Further testing is required with longer lengths of cord/webbing.

Future Questions:

1. How large of a static loop could be utilized that will still secure the weight? How will it behave?
2. Can a loop large enough to give clearance while raising the loop up the tree (without getting caught on rough bark) still secure the device without being tightened?
3. How large of a tightening loop will secure the device? How will it behave?

Setup:

Environmental Conditions:

- Dry, sunny day
- Temperature: 1ºC

Tree:

- Size:
  - Circumference = ~ 82 cm
    - Waist level = 85 cm (not installed at this height)
    - Eye level = 82 cm
    - Max height (my reach) = 81.5
    - this varies at different points of the tree (not constant)
  - Radius = 13.1 cm
  - Diameter = 26.1 cm
- Bark:
  - very rough
  - lots of grip

Static Cord:

- 8-9 mm static cord
- bite in one end with over hand knot
- other end over hand knot (no bite)
- length: bite to rope end (no knot) = 107 cm
- length (no knots) = 140 cm

Webbing:

- used TRX Suspension Anchor

1 nylon webbing with pre-made sown loops (similar to a daisy chain)
2 carabiner at the end
3 length:
webbing = 90 cm (~35.4 in)
6.5 cm carabiner
4 width = 3.7 cm (1.46 in)

Weight:

- A number of weights in a mesh bag attached to a screw gate carabiner
- 400g + 400g + 420g + 185g + 185g + carabiner (guess 85g?)
  - 1.59 kg = 3.498 lbs + carabiner
  - 1.675 kg = 3.658 lbs

Tests:

Test 1 - Webbing (tight)

- test with webbing as tight as possible with the setup
  - still enough space to fit hand behind webbing
  - 84 cm (on 82 cm tree)
  - Diameters: 26.7 cm (loop) on 26.1 cm (tree)
  - Radius space: 0.3 cm (has to be a bit more than this based in finger space)
    - not directly measured
- no slippage with weight
  - 3.66 lbs
- no slippage with body weight
  - ~ 134 lbs

Figure 5-1: "Tight" webbing spacing

Figure 5-2: "Tight" webbing on tree

Figure 5-3: "Tight" webbing with weight

Test 2 - Webbing with Slack

- Webbing adjusted to max size available
  - 94 cm (webbing + carabiner) on 82 cm circumference tree
  - Diameters = 29.9 cm (loop) on 26.1 cm (tree)
  - Radius space = 1.9 cm
    - Was not directly measured, but determined from diameter measurements
- no slippage with weight
  - 3.66 lbs
- no slippage with body weight
  - ~ 134 lbs

Figure 5-4: "Loose" webbing space

Figure 5-5: “Loose” webbing on tree

Figure 5-6: “Loose” webbing with weight

Test 3 - Static cord; Static loop; Initial test

- Initial test with static loop to see if it will hold the weight
    - bite tied in one end of the cord, with stopper knot tied on the other end
    - weight carabiner attached directly to cord
- Result:
    - Success: holds weight
        - no slippage with weight
            - 3.66 lbs
        - no slippage with body weight
            - ~ 134 lbs

Figure 5-7: Initial static cord test slack

Figure 5-8: Initial static cord weight test (zoom)

Figure 5-9: Initial static cord weight test

Test 4 - Static cord; Tightening loop; Initial test

- Initial test with tightening loop to see how it will hold the weight
  - bite tied in one end of the cord, with stopper knot tied on the other end
  - weight carabiner attached directly to end of stopper knot
- Result:
  - Success; holds weight
    - no slippage with weight
      - 3.66 lbs
    - no slippage with body weight
  - Does not self-tighten (static)
    - loop had to be tightened by tester
    - did not tighten under weight
  - Minor self-tighten with large drop
    - dropped weight multiple times with loop fully loosened
    - minor tightening of loop during drop
    - sometimes no tightening
    - seemed to be affected by when cord bites into tree trunk

Figure 5-10: Tightening loop; hand tightened

Figure 5-11: Tightening loop; not tightened

Test 5 – Static cord; Static loop; Drop tests

- Testing to see how initial position of weight prior to drop would affect the ability of a static loop of static cord to attach to the tree trunk
- Setup:
  - approximately 15 cm of radial slack in cord loop
- Test a): Weight it away from the tree trunk.
  - the cord loop on the opposite end of the tree trunk from the weight (device) is tight against tree trunk
  - simulate installation if device was pulled away from tree trunk as far as a pre-tied loop would allow
  - Result:
    - no measurable vertical drop in static cord
    - weight and cord secure

Figure 5-12: Static loop drop test slack measurement

Figure 5-13: Static loop drop test a); weight pulled away from tree trunk

Figure 5-14: Static loop drop test a); result

- Test b): Weight tight against tree trunk
  - the weight (device) is tight against the tree trunk with the cord loop on the opposite end of the tree trunk for the weight is loose
  - simulate installation if device was pushed tight against tree trunk
  - Result:
    - cord loop drops 18 cm
    - then secures to tree trunk
    - secures once cord loop on the opposite side of trunk makes contact with tree trunk

Figure 5-15: Static loop drop test b); weight against tree

Figure 5-16: Static loop test b); result (approx. 18 cm drop)

Appendix 5.2: Tree Cord Tests 2 – Large Loops

Synopsis:

Following the initial tests conducted in “Tree Cord/Webbing Tests 1”, a longer length of the same 9 mm static cord was utilized to explore of how large a loop could be employed to secure the weight to the tree trunk. The length was such that any desired sized loop could be tested. Tests were conducted on Feb. 24, 2016.

This was of interest with respect to design concepts that would require the cord/webbing to be pre-tied around the tree trunk on the ground, prior to raising the device. Based on initial field tests it was believed that such a setup would require a clearance between the cord/webbing and the bark of the tree trunk in order to raise the device (with the cord/webbing).

The ability of a large loop to secure a device without requiring the loop to be contracted around the tree trunk was also of interest as many concepts were in development to solve the problem of securing a tight loop of cord/webbing.

Questions:

1. Can a loop large enough to give clearance while raising the loop up the tree (without getting caught on rough bark) still secure the device without being tightened?
2. How large of a static loop will secure the device? How will it behave?
3. How large of a tightening loop will secure the device? How will it behave?

Results Summary:

General Summary:

- A tight loop of cord (loop diameter close to tree trunk diameter) is unnecessary to secure the device weight
- A static loop tied at the base of the tree is a viable installation/attachment method
- Where the back of the loop of cord makes contact with the tree trunk determined where the loop would lie on the tree trunk
- A dynamic loop tied at the base of the tree trunk is also a viable installation method, particularly when the device is pulled away horizontally from the tree trunk
- A dynamic loop could result in a large “tail” of cord descending from the main loop. This could be problematic for device installation purposes.
- A loop of cord with a diameter close to that of the tree would secure itself to the tree under simple free fall conditions. Installation procedures should be considered for a larger loop.
- A large loop requires support of the back end of the loop to ensure successful installation
- All setups tested were able to secure the weight of a full grown man (~134 lbs). Only the largest loop diameters experienced any slippage prior to the cord biting into the tree trunk.

Observations:

The size of the loop of cord did not appear to be a critical component in determining the holding power of the cord for the weights in question. The bark on the tree species was quite rough and provided excellent grip for the cord. There was no slippage experienced under the load of the “device” weight of ~3.7 lbs. Only with the largest loop was there slippage under the weight of a full grown man (~134 lbs).

For a static loop of cord this was encouraging, as a loop could be tied around a tree trunk at its base with sufficient clearance to allow the loop to be raised to the installation point without the cord making contact with the tree trunk (support for the cord would be required). Taking into account the reduction in a tree trunk’s diameter along its elevation, results still provide confidence that such a loop would reliably secure the device to the tree trunk, without the need to reduce the diameter of the cord loop. The friction in the system that is formed along the entire cord and tree trunk interface was sufficient to hold the device and additional weight.

The adequacy of the friction force was further supported in dynamic loop tests where once a device and loop were resting against the tree trunk the excess slack in the loop remained constant under the weight of the “device” weight.

The contact point between the back of the cord loop and the back of the tree trunk was observed to be an important factor in the behavior of the installation of the device. In general, once the back of the cord was in contact with the tree trunk that section of cord would be secure. A drop from the intended installation point and the final resting place of the loop of cord was determined by where the back of the cord loop first made contact with the tree trunk. In tests where the device was pulled away from the tree trunk prior to release (so that the back of cord loop was in contact with the tree trunk prior to release of the “device” weight) there was no observed drop in the cord placement. In such cases the displacement between the intended installation point and the resting position of the device were due solely to slack in the loop of cord.

For a dynamic loop it was observed that the installation method was a critical factor in determining the characteristics of the final loop assembly. An installation method where the device was pushed against the tree trunk, with the back of the loop of cord unsupported, would result in a loop resembling a static loop. An installation method where the device was pulled away from the tree trunk horizontally resulted in a tightly contracted loop.

A large dynamic loop constricted in this fashion has the result of a very long “tail”. This could be a cause for concern in the installation of a device if it was to be attached to the end of such a length of cord.

Loops of cord with a diameter relatively close to that of the tree trunk would secure themselves under free fall conditions once the cord made contact with the tree trunk.

For a loop of cord with a much larger diameter than the tree trunk at the installation point, the point of contact between the back of the loop and the tree trunk is of critical importance. In general, the loop should be supported to ensure that the back of the loop does not drop too far below the installation point and that contact is made at a reasonable location.

All installed loops were tested under weight of a grown man after initially secured to the tree trunk. In all cases but those with the largest delta in loop and tree trunk diameter was there any loop slippage observed. The case of slippage occurred with a large static loop where the loop slipped roughly 5 cm prior to biting into the tree trunk, at which point the weight was supported.

Future Questions:

1. How do cord/webbing hold up over time with applied weight?
   a. tight/small loop
   b. loose/large loop
   c. static/tightening
2. How do cord/webbing hold up to wet conditions
   a. tight/small loop
   b. loose/large loop
   c. static/tightening
3. How do these results apply to wire?

Setup:

Environmental Conditions:
Test were carried out over multiple days from Feb. 26 to Mar.2, 2016. The condition on test days were:

- Dry, sunny day
- Temperature: -2 to 1^{o}C

Test Tree

Properties:

- Bark:
  - very rough
  - lots of grip
- Straight trunk
- No branches in range of test area

Size:

- Circumference: ~ 130 cm
  - Waist level: 134.5 cm
  - Eye level: 131.5 cm
  - Max height (my reach): 128 cm
- Radius: 20.7 cm
- Diameter: 41.4 cm

Equipment

1. Static Cord:
   - 8-9 mm static cord
   - bite at free end with over hand knot
   - free end of line goes through the bite to form loop
   - the moveable bite along line is used to:
     - determine size of static loop
     - connection point for dynamic (tightening) loop
   - length: unlimited

2. Weighted Mesh Bag - Sm (Device simulation):
   - A number of weights in a mesh bag attached to a large screw gate carabiner
     - 1.675 kg = 3.658 lbs

3. Carabiners
   - x1 Large - 11.5 cm screw lock carabiner
     - 85 g
   - x1 Small - 10 cm screw lock carabiner

4. Measurement Instruments

- Metal Ruler – 30 cm
- Measuring Tape – 3 m

Figure 5-17: Test setup “A” with all gear

Tests

Test Setup

Two setups were tested at various lengths. In both setups a bite tied along the length of the line is moved along the line of cord to determine the size of the base loop.

Test setup “A” has the cord setup as a dynamic loop. The weight is attached to the loop via the bite tied along the length of the line. This setup allows the loop to constrict.

Test setup “B” has the cord setup in a static loop. The weight is attached either directly to the cord of the loop or to the bite tied in the free end. The bite along the length of the line is utilized to vary the base size of the loop. The loop is unable to constrict.

Tests were conducted with both the weight tight to the tree with the back end of the loop pulled away from tree trunk (loose) and with the weight pulled away from tree trunk with the back end of the loop in tight contact against the trunk of the tree. In each case the loop would be held away from the tree trunk horizontally, prior to the weight being dropped/lowered.

Body weight tests were conducted once the assemblies were at rest to see the effect of added weight and test the reliability of the hold.

Figure 5-18: Test setup "A"

Figure 5-19: Test setup “B”

Test 1 (22.5 cm radius slack)

The first test conducted utilized a loop diameter that was approximated to give adequate clearance to allow the avoidance of contact between the cord and the bark of the tree trunk while raising the loop, if there was proper loop support.

When raising the loop there was some interference with the bark, but this is thought to be mainly due to a lack of a support system. After testing it is concluded that a larger loop could be utilized.

Loop dimensions:

- Slack: ~22.5 cm radius from tree trunk to stretched loop
  - on a 20.7 cm radius tree trunk
- Loop circumference: 160 cm
- Loop diameter: 50.9 cm
  - 123% larger than tree diameter
- Loop radius: 25.5 cm

Figure 5-20: Test 1 slack

Test 1-A: Dynamic Loop

The starting position is such that the loop at maximum extension. This has the effect that both of the bites (knots) in the loop of cord are in contact.

Weight away from tree trunk – "Free Fall"

Setup:

- Weight is held at max horizontal distance away from the tree trunk
- Back end of loop is tight against tree trunk
- Weight is dropped – free fall

Results:

- Creates tail – 14 cm
- Back of loop drop - No cord slippage from initial position

- No slippage under body weight (~134 lbs)
- No further constricting of loop under body weight

Weight against tree trunk – “Pull Off”

Setup:

- Weight starts in contact with the tree trunk
- Back end of loop is loose, but supported (not hanging down)
- Weight is pulled away from tree trunk, horizontally
- Simulate if device was pushed up against tree for raising the device, and then pulled away from tree trunk when at installation site (elevation) to close loop

Results:

- Loop constricts smoothly
- Creates tail – 28 cml
- Back of loop drop – no major drop as back of loop is supported
    1. Cord remains in position of initial contact with tree trunk
    2. No further cord slippage once initially secured
- No slippage under body weight (~134 lbs)
- No further constricting of loop under body weight

Weight against tree trunk – “Drop”

Setup:

- Weight starts in contact with the tree trunk
- Back end of loop is loose, but supported (not hanging down)
- Both device and loop are released simultaneously

Results:

- Creates tail – 8 cm
- Back of loop drop - falls 33 cm
    - distance of assembly fall prior to the cord catching on the tree trunk
- Final assembly distance from upper cord to device knot – 38 cm
    - Due to slack in the system
- No slippage under body weight (~134 lbs)
- No further constricting of loop under body weight

Figure 5-21: Test 1A, “Free Fall” result

Figure 5-22: Test 1A, "Free Fall" tail

Figure 5-23: Test 1A, "Pull Off" result

Figure 5-24: Test 1A, "Pull Off" tail

Figure 5-25: Test 1-A, “Drop” result

Test 1-B: Static Loop

Tests were conducted with the "device" weight attached to both the static bite and directly to the loop cord. There was no effect on the results.

Weight away from tree trunk, free fall device

Setup:

- Weight is held at max horizontal distance away from the tree trunk
- Back end of loop is tight against tree trunk
- Weight is dropped – free fall

Results:

- Back of loop drop – no cord slippage from initial position during free fall of device
- Distance from upper cord to device knot – 37 cm
    - Vertical distance of device drop
- No cord slippage under "device" weight (3.7 lbs)
- Slight cord slippage under full body weight (~134 lbs), before biting into bark
    - supports full body weight
- *Weight against tree trunk, free fall device*

Setup:

- Weight starts tight against tree trunk
- Back end of loop is loose, but supported (not hanging down)
- Entire assembly is dropped simultaneously

Results:

- Cord/device weight assembly falls down tree trunk (vertically) until the back end of the cord makes contact with the tree trunk
- Back of loop drop – once contact is made with tree trunk, no slippage
    - Distance before contact – 19 cm
- Distance from upper cord to device knot – 43 cm
    - Vertical distance of device drop
- No cord slippage under "device" weight (3.7 lbs)
- No cord slippage under full body weight (~134 lbs)

Weight away from tree trunk, control lower device

Simulates pole installation.

Setup:

- Weight is held at max horizontal distance away from the tree trunk
- Back end of loop is tight against tree trunk
- Weight is slowly lowered in a controlled manner

Results:

- Very smooth installation – perfect

- Back of loop drop – no slippage
- Distance from upper cord to device knot – 43 cm
    - Vertical distance of device drop
- No cord slippage under “device” weight (3.7 lbs)
- No cord slippage under full body weight (~134 lbs)

Figure 5-26 1: Test 1-B, Weight away from tree trunk, free fall device - results

Figure 5-27: Test 1-B, Weight against tree trunk, free fall device - results

Figure5-28: Test 1-B, Weight away from tree trunk, control lower device - results

Test 2 (50 cm radius slack)

The second test explored a loop diameter that was judged to give more than excess clearance to allow the avoidance of contact between the cord and the bark of the tree trunk while raising the loop. Loop support would be required to prevent the loop from dragging behind. It was rationalized that if a loop of this exaggerated size would function to support the weight, than no larger loop would be required.

Loop dimensions:

- Slack: Approximately 50 cm radius from tree trunk to stretched loop
    - on a 20.7 cm radius tree trunk
    - 2.66 times more slack radius than tree radius
- Loop circumference: 229 cm
- Loop diameter: 72.9 cm
    - 176% larger than tree diameter
- Loop radius: 36.4 cm

Figure 5-29: Test 2 slack

Test 2-A: Dynamic Loop

The starting position is such that the loop at maximum extension. This has the effect that both of the bites (knots) in the loop of cord are in contact.

<u>Weight away from tree trunk – "Free Fall"</u>

Setup:

- Weight is held at max horizontal distance away from the tree trunk
- Back end of loop is tight against tree trunk
- Weight is dropped – free fall
- Successful test conducted at 215 cm above ground
    - Previous test at 190 cm resulted in the weight hitting the ground

Results:

- Creates tail – 68 cm
- Back of loop drop – 4 cm
- No slippage under body weight (~134 lbs)
- No further constricting of loop under body weight

<u>Weight against tree trunk – "Pull Off"</u>

Setup:

- Weight starts in contact with the tree trunk
- Back of loop is loose behind tree trunk; tested in two methods
    1. Not supported
    2. Supported (hand)
- Weight is pulled away from tree trunk, horizontally
- Simulate if device was pushed up against tree for raising the device, and then pulled away from tree trunk when at installation site (elevation) to close loop
- Test conducted from 215 cm above ground

Results:

1. Not Supported back loop
    - Despite the constricting motion of pulling the device away from the tree, without support the back of the loop falls far below the device height.
    - The cord never takes hold of the tree trunk
    - Device ends up falling to the ground
    - Failed installation
2. Supported back loop
    - Loop constricts smoothly
    - Creates tail – 87 cm
        - Much larger tail versus test 1-A (28 cm)
    - Back of loop drop – no major drop as back of loop is supported

  - Cord remains in position of initial contact with tree trunk
  - No further cord slippage once initially secured
- No slippage under body weight (~134 lbs)
- No further constricting of loop under body weight

<u>Weight against tree trunk – "Drop"</u>

Setup:

- Weight starts in contact with the tree trunk
- Back end of loop is loose, but supported (not hanging down)
- Both device and loop are released simultaneously

Results

- Bottoms out (hits the ground) before the loop catches on tree trunk
  - Partially due to the low height of tests
- Loop does constrict, but not enough to become "tight"
  - Possible that at greater elevation the loop would constrict enough for the loop to catch on the tree trunk
- Tested at elevation of 215 cm

Figure 5-30 2: Test 2-A, Weight away from tree trunk – "Free Fall" - setup

Figure 5-31: Test 2-A, Weight away from tree trunk – "Free Fall" - result

Figure 5-32: Test 1-B, Weight against tree trunk – “Pull Off”- not supported - result

Figure 5-33: Test 1-B, Weight against tree trunk – “Pull Off” – supported - result

Figure 5-34: Test 1-B, Weight against tree trunk – “Drop” - results

Test 2-B: Static Loop

Tests were conducted with the “device” weight attached to both the static bite and directly to the loop cord. There was no effect on the results.

Weight away from tree trunk, free fall device

Setup:

- Weight is held at max horizontal distance away from the tree trunk
- Back end of loop is tight against tree trunk
- Weight is dropped – free fall

Results:

- Sits nicely on the tree trunk, despite large loop
- Back of loop – cord slips 5 cm
- No cord slippage under “device” weight (3.7 lbs)
- Cord slippage under full body weight (~134 lbs),

Weight against tree trunk, free fall device

Setup:

- Weight starts tight against tree trunk
- Back end of loop is loose, but supported (not hanging down)
- Entire assembly is dropped simultaneously

Results

- Bottoms out (hits ground) before the loop catches on tree trunk
  - Partially due to the low height of tests
- Loop does constrict, but not enough to become “tight”
  - Possible that at greater elevation the loop would constrict enough for the loop to catch on the tree trunk
- Tested at elevation of 215 cm

Figure 5-353: Test 2-B, Weight away from tree trunk, free fall device - setup

Figure 5-36: Test 2-B, Weight away from tree trunk, free fall device - result

Figure 5-37: Test 2-B, Weight against tree trunk, free fall device- result

Test 3 – Extreme Case

As an extreme example of a loop much larger than the tree trunk diameter the 72.9 cm diameter loop from Test 2 was used on the 26.1 cm diameter tree from "Tree Cord/Webbing Tests 1".

Loop dimensions:

- loop circumference: 229 cm
- loop diameter: 72.9 cm
    - 279% larger than tree diameter

Test 3-A: Dynamic Loop

Tests were not performed on a dynamic loop as it was not possible to raise the starting point to an elevation where it would be possible for the weight to not hit the ground, based on previous tests.

Test 3-B: Static Loop

The test was performed at the end of the day as a quick experiment to see if a static loop of that size would hold. As such no specific measurements were taken.

<u>Weight away from tree trunk, free fall device</u>

Setup:

- Weight is held at max horizontal distance away from the tree trunk
- Back end of loop is tight against tree trunk
- Weight is dropped – free fall

Results:

- Sits nicely on the tree trunk, despite large loop
- Back of loop
- No cord slippage under "device" weight (3.7 lbs)
- Cord slippage under full body weight (~134 lbs),

<u>Weight against tree trunk, free fall device</u>

This setup was not tested as after previous configurations of this test had the weight hitting the ground before the large loop could grip the tree.

Figure 5-38: Test 3-B, Weight away from tree trunk, free fall device - result